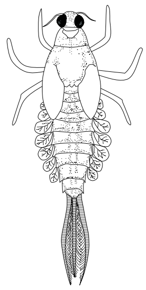
Stream Invertebrates of Banks Peninsula, New Zealand



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ABSTRACT

For the majority of the last 20 Ma Banks Peninsula existed as an isolated island from the rest of New Zealand. As a result, numerous endemic species have evolved in this isolated region. Regional endemism has been recorded in plant, insect, and bird species. Unfortunately, a number of these species may now be extinct. Prior to human arrival the Peninsula was almost completely covered in dense mixed podocarp forest. However, human deforestation reduced indigenous forest on the Peninsula to < 1 % of its original coverage. Now native forest and scrub cover an estimated 15 % of Banks Peninsula (much of this is regenerated). Currently, Banks Peninsula has 10 regionally endemic stream invertebrates (nine formally described), which are all classified as 'threatened' or 'at risk'. However, the conservation status of many New Zealand stream invertebrates is limited by a lack of scientific knowledge. Prior to this study it was unknown whether Banks Peninsula's regionally endemic stream invertebrates were restricted to a few catchments and highly threatened or if they were just poorly studied. Previous work had indicated that several of the Peninsula's endemic species were restricted to forested headwaters and forest fragments.

The primary aim of this study was to determine the distribution of Banks Peninsula's regionally endemic stream invertebrates. Secondly, my study aimed to test whether regional and river classifications could explain the spatial distribution of these endemic species. Lastly, I aimed to assess stream invertebrate diversity across three spatial scales and determine whether selected taxa (including endemic species) showed specific microhabitat preferences on the Peninsula. I carried out a survey of 54 streams spatially separated across Banks Peninsula. At each stream benthic invertebrates were collected, and physico-chemical parameters were measured. To my knowledge this is the largest scale survey that has been carried out specifically assessing Banks Peninsula's regionally endemic stream invertebrates.

I collected seven of the 10 known endemic species. Two endemic species, the caddisfly *Hydrobiosis styx* and the stonefly *Zelandobius wardi* were found in all three of the Peninsula's Ecological Districts. However, the other five species I collected, including the caddisfly *Costachorema peninsulae,* the mayfly *Nesameletus vulcanus,* the net-winged midge *Neocurupira chiltoni,* the beetle *Orchymontia banksiana,* and the undescribed stonefly *Zelandoperla* sp.1 (BJF00160: Banks Peninsula) were restricted to Akaroa and Herbert Ecological Districts. Two species (*O. banksiana* and *N. chiltoni*) were common and widely distributed across the Peninsula. However, the remaining five endemics occurred in isolated, scattered, and small sub-populations, which probably reflect the areas historic deforestation.

The endemic species tended to occur in two main community groups. While *N. chiltoni, O. banksiana,* and *C. peninsulae* were characteristic of communities that occurred in larger, non-forested streams. *H. styx, N. vulcanus, Z. wardi,* and *Zelandoperla* sp. 1 preferred smaller higher altitude streams with higher amounts of native riparian vegetation and shading. Further, analysis using the River Environment Classification (REC) suggested that these seven endemic species occur commonly in cold wet environments within steep small to medium sized streams sourced from hills. In contrast the third classification system I tested, the Freshwater Ecosystems of New Zealand (FWENZ), was not able to robustly explain the occurrences of the majority of these endemic species.

I also investigated diversity across the Peninsula at three scales – alpha (local or stream diversity), beta (catchment) and gamma (regional). I collected a total of 95 taxa. This high diversity is similar to the stream invertebrate diversity of other much larger ecoregions in New Zealand. Alpha diversity showed a significant pattern of increasing from the north and west towards the south and east. Local stream diversity was most strongly associated with larger streams (wider, faster velocities, and deeper). However, the absence of clear patterns between beta diversity and measured physico-chemical parameters suggests that larger scale environment heterogeneity is influencing beta diversity. Endemic species accounted for 7 % of the Peninsula's (gamma) diversity and up to 21 % the diversity in individual streams (alpha diversity). Furthermore, several of the regionally endemic species showed strong preferences for specific microhabitats, particularly riffles, suggesting these endemics are highly adapted to the Peninsula's steep gradient streams.

Lastly, I review the conservation status of seven regionally endemic stream invertebrates. Based on my assessment, the status of *N. vulcanus* and *Z. wardi* is better than currently listed and their classification could be changed to 'Nationally Vulnerable'. The status of four endemic species (*C. peninsulae, H. styx, N. chiltoni,* and *O. banksiana*) seemed appropriate. However, my results indicate that *Zelandoperla* sp. 1 should have a higher threat status and be reclassified as 'Nationally Endangered'. Although forested headwater streams on the Peninsula do not have as diverse habitats as larger lowland streams, they contributed markedly to the diversity of Banks Peninsula and are important habitats for the regionally endemic species. Therefore, the protection of forested headwaters is critical to preserve the diversity of Banks Peninsula and it's regionally endemic stream invertebrates.

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Chapter one: Introduction

1.1 Freshwater invertebrate endemism in New Zealand

New Zealand's freshwater invertebrate fauna is characterised by high endemism, a pattern similar to the rest of the country's biota. Due to New Zealand's early separation from Gondwana and more recent volcanic, seismic, and glacial activity, an estimated 90 % of our freshwater invertebrates are endemic (Boothroyd, 2000, Harding, 2005). Furthermore, a number of New Zealand's freshwater invertebrates are 'range restricted', meaning they are confined to areas less than 100 000 ha (Collier, 1993, Townsend et al., 2008, Grainger et al., 2018). A number of regions throughout the country also show particularly strong regional endemism, such as Nelson, Fiordland, and Banks Peninsula in the South Island (McLellan, 1990).

New Zealand's freshwater invertebrate fauna are markedly different to those in the Northern Hemisphere. In New Zealand some groups are missing or poorly represented (Collier, 1993). Most of our freshwater invertebrate families are limited to New Zealand or the Southern Hemisphere. For example, New Zealand's mayfly diversity is restricted to only 57 endemic species and is dominated by the family Leptophlebiidae (Collier, 1993, Pohe, 2019), while North American mayflies are dominated by the family Baetidae (Collier, 1993) and consists of hundreds of taxa. All of New Zealand's stoneflies are endemic and have smaller body sizes compared to Northern Hemisphere stoneflies (Collier, 1993). Additionally, New Zealand also has an unusual number of flightless stoneflies (McCulloch et al., 2009, Veale et al., 2018). The long-standing isolation of New Zealand from other countries is the most likely driver of the endemism and community composition seen amongst our freshwater invertebrates (Collier, 1993).

1.2 Status of New Zealand's freshwater invertebrates

New Zealand is recognised internationally for having a well-developed understanding of its freshwater invertebrate life histories, distributions, and ecology (Strayer, 2006). However, much is still unknown about our stream invertebrates. New Zealand's freshwater invertebrate conservation decisions are often hampered by a lack of robust information. It was not until 1992 that the first attempt was made to classify threatened New Zealand freshwater invertebrates (Collier, 1993). Although 675 freshwater invertebrates are now included in the New Zealand threat classification, 178 of these taxa have insufficient data to be assigned a conservation status based on the limited knowledge of their distribution and populations (Table 1.1) (Grainger et al., 2018). Furthermore, an additional 88 species are listed as 'data poor', meaning the confidence of these species classifications is low because there is only poor information available for their assessment (Townsend et al., 2008, Grainger et al., 2018). Therefore, 39 % of New Zealand's freshwater invertebrate taxa currently have significant gaps in their scientific knowledge. Currently 26 % of New Zealand's freshwater invertebrates are considered as 'at risk' or worse (Table 1.1). The number of 'threatened' and at 'risk taxa' is only expected to grow as our knowledge of freshwater invertebrates increases. On top of this, new species are regularly being discovered in New Zealand. In just four years between the publications of Grainger et al. (2014) and Grainger et al. (2018) 40 more species were added to the New Zealand threat classification list and assessed for the first time.

Table 1.1: Conservation status of New Zealand's freshwater invertebrates assessed by Grainger et al. (2018) compared to the 10 regionally endemic stream invertebrates of Banks Peninsula as listed by Andrew et al. (2012) and Grainger et al. (2018).

Conservation status	National status	Regionally endemic Banks Peninsula
Data Deficient	178	
Threatened – Nationally Critical	48	2
Threatened – Nationally Endangered	14	3
Threatened – Naturally Vulnerable	16	4
At Risk - Declining	10	
At Risk – Naturally Uncommon	89	1
Not Threatened	315	
Non-resident native – Coloniser	2	
Non-resident native – Vagrant	1	
Introduced and naturalised	2	
Total number of taxa assessed	675	10

1.3 Banks Peninsula

Banks Peninsula extends into the Pacific Ocean from the east cost of the South Island, New Zealand. The Peninsula covers approximately 100 000 hectares and rises to 920 m a.s.l. (Wilson, 1992). The Peninsula first formed as a low-lying island off the coast of Zealandia during the Kaikoura Orogeny and Southern Alps uplift, around 20 Ma (Soons et al., 2001). Between 11 and 5.8 Ma the island was volcanically active (Hampton and Cole, 2009). This volcanic activity can be divided into four periods; Lyttelton (11-9.7 Ma), Akaroa (9.3-8 Ma), Mt Herbert (9.7-8 Ma), and later volcanism on the flanks the degraded volcanoes and in Diamond Harbour (8.1-5.8 Ma) (Hampton and Cole, 2009). The current topography of the Peninsula reflects a combination of the underlying volcanic structures and subsequent erosion (Hampton and Cole, 2009). Many of the erosional features (e.g. valley and ridge patterns) are controlled by relict volcanic structures, such as the eruptive centres in Lyttelton Harbour (Hampton and Cole, 2009).

Banks Peninsula has alternated between isolation and connection to the mainland since at least the late Quaternary through phases of glacial and interglacial cycles (Soons et al., 2001). The uplift of the Southern Alps and subsequent deposition of alluvial gravels across the Canterbury Plains ended Banks Peninsula's isolation (Timm et al., 2009). A permanent connection had developed between the volcanic island and mainland New

Zealand by the end of the last ice age (the Otira Glaciation), around 20,000 years ago (Soons et al., 2001, Wilson, 2013a). During this time the Peninsula was close enough to the mainland to share both animal and plant species (Soons et al., 2001, Wilson, 2013a), but also isolated enough to maintain regionally endemic linages, especially of insects such as the stonefly *Zelandobius* (McCulloch et al., 2016).

Soil horizons preserved on Banks Peninsula between volcanic phases, suggest from very early in the Peninsula's formation vegetation was present (Wilson, 1992, Wilson, 2013a). Woody vegetation survived on the Peninsula through the late Quaternary (Soons et al., 2001) and provided refuge to a number of insects and plants during the last glacial maximum (Buckley et al., 2009, Buckley et al., 2010, Wilson, 2013b, Wisemana et al., 2016). Prior to Polynesian arrival in the 13th century the Peninsula was covered in warm temperate forest, dominated by podocarps (e.g. *Podocarpus totara, Prumnopitys taxifolia,* and *Dacrycarpus dacrydioides*), hardwoods, tree ferns, and nīkau palm (*Rhopalostylis sapida*) (Wilson, 2013b).

Streams on the Peninsula are short, steep and form radially around the volcanic centres (Hampton and Cole, 2009). Based on the River Environment Classification (REC) (Snelder and Biggs, 2002) there is over a 1000 1st order streams, more than 200 2nd order streams, 38 3rd order streams, and three 4th order streams on Banks Peninsula. A number of small streams, particularly in the north-western of the Peninsula are ephemeral. However, most of the Peninsula's waterways flow permanently from small springs (Wilson, 2013a). Southern and high altitude areas of the Peninsula receive a greater annual rainfall, which can range between 750 and 2000 mm per year across the Peninsula (Wilson, 2013a).

1.4 Banks Peninsula's regional endemism

The longstanding isolation and volcanic landscape of the Peninsula has resulted in the development of regional endemism in the Peninsula's flora and fauna. The Peninsula is home to over 30 known terrestrial and aquatic regionally endemic species. These regionally endemic species include a daisy (*Celmisia mackaui*), the Banks Peninsula hebe (*Veronica strictissima*), a tussock (*Festuca actae*), a spider (*Periegops suterii*), the Akaroa tree wētā (*Hemideina ricta*), numerous terrestrial beetles (e.g. *Mecodema howitti*), a subspecies of blue penguin, and 10 species (nine described) of stream invertebrates (Anderson et al., 2003, Harding, 2003, Bowie et al., 2010, Bowie et al., 2011, Wilson, 2013a, Department of Conservation, 2015, Grainger et al., 2018). The endemic stream invertebrates include five caddisflies: *Costachorema peninsulae* (Ward, 1995), *Edpercivalia banksiensis* (McFarlane, 1939), *Hydrobiosis styx* (McFarlane, 1951), *Tiphobiosis childella* (Ward, 1995), and *Tiphobiosis hinewai* (Ward, 1995). A single Blephariceridae (*Neocurupira chiltoni* (Campbell, 1921)), one mayfly (*Nesameletus vulcanus* (Hitchings and Staniczek, 2003)), one feather-winged beetle (*Orchymontia banksiana* (Ordish, 1984)), and the stonefly *Zelandobius wardi* (McLellan, 1993). Recently a regionally endemic stonefly from the

Zelandoperla genus has also been recognised on the Peninsula (McCulloch et al. (2009), McCulloch et al. (2016), B. Foster, personal communications, 2019). Banks Peninsula's close proximity to the mainland means it shares many species with mainland New Zealand. However, there have been limited investigations into the endemic stream invertebrates of Banks Peninsula, and it is likely there are other unknown species present in the region's streams (Johns, 1986).

Despite Banks Peninsula's high levels of endemism, we lack critical knowledge about the distribution, abundance, and preferential habitat of these endemic stream invertebrates. Almost all of Banks Peninsula's endemic stream invertebrates are classified as 'threatened' (Table 1.1) (Grainger et al., 2018). These endemic species are considered to be 'range restricted' occurring in an area < 100 000 ha, are 'data poor', have 'sparse', small, and poorly distributed populations, and in some cases are only known from 'one location' (Townsend et al., 2008, Andrew et al., 2012, Grainger et al., 2018). Currently there is some indication that Banks Peninsula's endemic stream invertebrates favour small forested headwater streams and are absent in larger lowland streams (Harding, 2003). However, the few studies into the Peninsula's stream invertebrates have perhaps resulted in more questions than answers regarding the distribution of these endemic species. Understanding the distribution and vulnerability of freshwater invertebrates is critical for ensuring future conservation efforts are well directed.

1.5 Environmental and biological threats to freshwater invertebrates

Globally freshwater invertebrates are facing numerous threats, spanning from habitat degradation to exotic species invasion and climate change (Dudgeon et al., 2006, Strayer, 2006, Strayer and Dudgeon, 2010). Currently between 10,000 and 20,000 freshwater species worldwide are estimated to be either 'at risk' of extinction or are 'threatened' by extinction (Vörösmarty et al., 2010). Some authors suggest rates of freshwater species extinctions are similar to those that have occurred during the geological epoch transitions (Vörösmarty et al., 2010). One reason for this loss of species is because freshwater environments are particularly vulnerable to habitat change as they reflect their surrounding terrestrial environment and upstream conditions (Hynes, 1975). As Hynes (1975) simply put it "the valley rules the stream". By this he meant freshwater ecosystems are intrinsically linked to their surrounding terrestrial environment through factors such as vegetation and landform. The impacts of land use and anthropogenic activities are widely known to alter the hydrology, water quality, and sedimentation of streams, which all impact stream biota (Allan, 2004).

Habitat loss through the development of agricultural, industrial, urban, and economic land in conjunction with deforestation has had major impacts on freshwater invertebrates in New Zealand (Collier, 1993, Quinn, 2000, Harding, 2003, Harding et al., 2006). New Zealand has lost 71 % of its original indigenous forest (Ewers et al., 2006), thus leaving only 51 % of the country's rivers and streams flowing through natural vegetation (Ministry for the Environment, 2007). In particular lowlands, densely populated areas, land adjacent to road networks, and the east coast of the South Island have been extensively deforested (Ewers et al., 2006). Banks Peninsula is no exception and has been subject to very high levels of historic deforestation.

Prior to human settlement much of Banks Peninsula was dominated by podocarp forest. Between Polynesian and European arrival (around 1830) roughly a third of the Peninsula's original forest was destroyed by fire, particularly in the north west (Burrows, 1998, Wilson, 2013b). By 1920, less than 100 years after European settlement, extensive logging and fires had reduced old-growth podocarp forest on the Peninsula to < 1 % of its original cover (Burrows, 1998, Harding, 2003, Ewers et al., 2006, Wilson, 2013b). It has been estimated that more than half of the Peninsula's native birds became locally extinct during this period of deforestation (Diamond, 1984). Naturally low abundance species such as kaka (*Nestor meridionalis*), were more prone to extinction as forested fragmentation increased on the Peninsula (Diamond, 1984). Many other plants and insects probably failed to persist through the deforestation of the Peninsula (Wilson, 2013b). However, the full impact of the Peninsula's deforestation to regions biodiversity will probably never be known. Since the 1920's the rate of forest clearance has reduced (Burrows, 1998, Wilson, 2013b). Native forest and shrublands predominately of kānuka (*Kunzea ericoides*) have begun to regenerate and by 2013 around 15% of the Peninsula was estimated to be covered in native forest or shrubland (Wilson, 2013b). However, most of the land above 300 m is dominated by tussock and lowlands are predominantly still farmed and are in pasture.

Habitat loss through deforestation has been suggested as the single biggest threat to the stream invertebrates on Banks Peninsula (Harding, 2003). Although there is no record of invertebrate loss during the Peninsula's deforestation, logging and forest fires would have caused severe impacts to the stream invertebrate communities during this period (Harding, 2003). Although there has been an effort to identify and recognise the many endemic species of Banks Peninsula, it is possible that some species never survived the intense deforestation of the Peninsula (Diamond, 1984, Wilson, 1992, Harding, 2003).

Agriculturally affected areas are widespread in Canterbury. The development of pasture and water diversion in Canterbury has extensively altered stream habitats, resulting in invertebrate community shifts (Quinn, 2000). One of the biggest ongoing effects of the Peninsula's deforestation and agricultural development is sedimentation and mass wasting. The volcanic rock of Banks Peninsula is covered by fine loess material (windblown sediment) that is easily eroded (Yates et al., 2018). Although stream invertebrates are able to withstand periodic increases in sediment, anthropogenic induced sedimentation can range from disruption of benthic feeding to escalated impacts such as smothering (Ryan, 2010). Suspended sediment can reduce the primary productivity, food chain length, and clarity of streams (Ryan, 2010). Additionally, high sedimentation can also increase invertebrate drift rates, lower productivity, reduce habitat for attaching organisms (e.g. black flies), and increase mortality (Ryan, 2010). Research carried out by Stone and Wallace (1998) suggests that invertebrate communities take in excess of 16 years to recover from deforestation to pre-logging levels even when the logged forest is replanted. Furthermore, work by Harding et al. (1998) indicates historic agricultural land use limits present day stream invertebrate communities and reduces the capacity for stream recovery. In other words, invertebrate communities in regenerating forested streams may still reflect agricultural or unforested conditions decades after adjacent land use has improved (Harding et al., 1998). These studies suggest Banks Peninsula streams may take decades to recover from deforestation and agriculture despite widespread native forest regeneration. Potentially some streams may never completely recover.

Although the greatest threat to freshwater invertebrates on Banks Peninsula is deforestation, invasive species and climate change may also impact the freshwater invertebrate fauna. Many anthropogenic alterations to waterways facilitate the dispersal, establishment, and persistence of invasive species. In New Zealand introduced salmonids are a considerable threat to native invertebrates (Townsend, 1996). The introduction of these freshwater sportfish into lakes and streams in New Zealand has resulted in widespread predation on indigenous invertebrate and fish species (Townsend, 1996). Although some suggest the impact of salmonids on native fauna is difficult to fully quantify (Collier, 1993, Dudgeon et al., 2006), large easily visible invertebrates (e.g. mayflies *Oniscigaster* and *Nesameletus*) are known to be more vulnerable to salmonid predation (Collier, 1993, McIntosh, 2002). The geographic range of salmonids in New Zealand is still increasing and many small order streams now have resident salmonid populations (Jones and Closs, 2017).

Pressures on freshwater ecosystems are becoming further compounded by climate changes. Many freshwater invertebrates are poor dispersers and will be unable to shift to suitable habitats as temperatures increase and fragmentation increases (Strayer, 2006). Freshwater insects with a flighted life stage have higher chances of dispersing and colonising new suitable habitats in the face of climate change (Strayer, 2006), providing both the species and habitats still exist. Watersheds at mid-latitudes tend to have highly developed endemism (Strayer and Dudgeon, 2010), making them some of the most vulnerable streams to climate change, especially where human impacts are prevalent (Strayer, 2006). New Zealand's mid-latitude location, long isolation, and highly developed endemism may combine to make our species particularly vulnerable to climate change. Climate change impacts are likely to be further heightened on Banks Peninsula because there are strong legacy effects from human impacts and high levels of regional endemism.

1.6 Research questions, hypothesis, and thesis structure

Currently all of Banks Peninsula's regionally endemic stream invertebrates are classified as 'threatened' or 'at risk'. However, there is little information on the distribution and habitat preferences of these species. There is some indication these species prefer forested streams (Harding, 2003), but not enough is known on these species to guide their protection. This study aims to increase the knowledge of these regionally endemic stream invertebrates to guide their conservation. This thesis is constructed around three main research questions and two data chapters, which are intended to be publish as individual papers. Therefore, there is some material overlap between the chapters.

Research questions:

1) What is the spatial distribution of Banks Peninsula's regionally endemic stream invertebrates and what environmental variables associate with their occurrences?

This question is addressed in chapter two of the thesis. Based on previous research by Craig (1969) and Harding (2003) I hypothesised that *Neocurupira chiltoni* would be the only endemic species to occur commonly across Peninsula. The other nine endemic species were expected to have small restricted distributions and show some associations with native vegetation and stream shading (Ward, 1995, Harding, 2003, Hitchings and Staniczek, 2003).

2) Can conservation classifications such as Ecological Districts, the River environment Classification, and the Freshwater Ecosystems of New Zealand be used to explain the spatial distribution of regionally endemic stream invertebrates on Banks Peninsula?

This research question is address in chapter two. Three multivariate classifications (Ecological Districts, River Environment Classification, and Freshwater Ecosystems of New Zealand) commonly used in New Zealand for biodiversity management, were used to classify streams on Banks Peninsula. These classifications were used to see if they could explain the spatial distribution of regionally endemic species. I hypothesised that the endemic species would be associated with districts, river environments, and ecosystems with high amounts of native vegetation. Banks Peninsula's Ecological Districts were expected to explain broad scale patterns of the endemic species distributions, while the River Environment Classification and the Freshwater Ecosystems of New Zealand were expected to explain some of the variation in the endemic species distribution based on the success of other studies assessing the distribution of stream invertebrate communities at ecoregion scales (e.g. Chakraborty (2008)).

3) What is the structure and diversity of stream invertebrate communities on Banks Peninsula? Do regionally endemic species have an important role in the community? What are the environmental main drivers of stream invertebrate communities on the Peninsula and do certain key taxa prefer particular microhabitat environments? These questions are addressed in chapter three of this thesis. I hypothesised that stream invertebrate diversity was to be highest in catchments to the east and south of the Peninsula, where native forest is more common. The Peninsula's community composition was expected to be associated with shading and native vegetation. No chemical variables were expected to be able to explain the variation in invertebrate diversity. Certain key species were expected to favour particular microhabitat environments, particularly riffles. For example, *Neocurupira chiltoni* were expected to occur more often in fast flowing habitats, such as riffles and runs based of habitat preferences outlined by Craig (1969).

Following from chapters two and three, chapter four provides a synthesis of the research in this thesis, along with implications and limitations of this research. chapter four also addresses the ongoing conservation and future threats on Banks Peninsula. Lastly, in chapter four I have taken a different approach using the River Environment Classification and my research findings to review the conservation status of the Peninsula's regionally endemic stream invertebrates.

Chapter Two:

The distribution of Banks Peninsula's regionally endemic stream invertebrates

2.1 INTRODUCTION

2.1.1 Banks Ecological Region and endemism

Banks Peninsula's close proximity to the Canterbury Plains means it shares many species with the rest of the South Island. However, the Peninsula's isolation for the majority of the last 20 Ma combined with the region's unusual combination of geology, topography, and climate has allowed regional endemism to develop. The Peninsula is home to over 30 regionally endemic species, of which roughly a third are freshwater stream invertebrates (Anderson et al., 2003, Harding, 2003, Bowie et al., 2010, Bowie et al., 2011, Wilson, 2013a, Department of Conservation, 2015, Grainger et al., 2018). For these reasons Banks Peninsula has been classified as one of New Zealand's 85 freshwater ecoregions (Harding and Winterbourn, 1997). Banks Peninsula's distinct freshwater ecoregion is driven by the areas volcanic rock, erodible loess soils (windblown fine glacial material), relief, and climate (Harding and Winterbourn, 1997).

2.1.2 Regionally endemic stream invertebrates

Currently there are 10 known (nine formally described) regionally endemic freshwater invertebrates on Banks Peninsula. There are five caddisflies: *Costachorema peninsulae* (Ward, 1995), *Edpercivalia banksiensis* (McFarlane, 1939)*, Hydrobiosis styx* (McFarlane, 1951)*, Tiphobiosis childella* (Ward, 1995), and *Tiphobiosis hinewai* (Ward, 1995). The other four described endemic species include a Blephariceridid (*Neocurupira chiltoni* (Campbell, 1921)), a mayfly (*Nesameletus vulcanus* (Hitchings and Staniczek, 2003)), a Hydraenidae beetle (*Orchymontia banksiana* (Ordish, 1984)), and a stonefly (*Zelandobius wardi* (McLellan, 1993)). Additionally, there is strong evidence suggesting there is a second regionally endemic stonefly on the Peninsula belonging to the *Zelandoperla* genus.

Initially when McLellan (1999) raised *Zelandoperla pennulata* to a species level from a subspecies of *Zelandoperla fenestrata,* nymphs examined from Banks Peninsula were described as having distinctive differences from other South Island populations of *Z. pennulata.* McLellan (1999) suggested that the stonefly may have evolved separately on the Peninsula*.* However, at the time a lack of adult material from Banks Peninsula prevented further investigation. Recent genetic evidence has shown that the Banks Peninsula *Zelandoperla* species is genetically distinct from other South Island and Stewart Island taxa belonging to the *Zelandoperla fenestrate* species group (McCulloch et al., 2009, McCulloch et al., 2016, Veale et al., 2018). The adult of the Banks Peninsula *Zelandoperla* sp. is flightless (McCulloch et al., 2009, Veale et al., 2018). This Banks Peninsula stonefly is suspected to have evolved from flighted individuals during the Pleistocene, roughly 10 Ma (McLellan, 1999, McCulloch et al., 2009, McCulloch et al., 2016). The Banks Peninsula *Zelandoperla* sp. is already recognised in the New Zealand Threat Classification as a new species, *Zelandoperla* sp. 1 (BJF00160; Banks Peninsula) (Grainger et al., 2018). At the time of writing there is no published information on the distribution and ecology of the stonefly, which is expected to be formally described in 2019-2020 (B. Foster, personal communication, 2019). Given the distinctive genetic and morphological differences already recognised in the Banks Peninsula *Zelandoperla* sp., combined with the longstanding isolation of the Peninsula and the high level of regional endemism, *Zelandoperla* sp. 1 (BJF00160; Banks Peninsula) will be treated as a regionally endemic species in this study.

Currently all of the Peninsula's regionally endemic stream invertebrates (except *N. chiltoni*) are classified as 'threatened' under the New Zealand Threat Classification system (Grainger et al., 2018). Two species are regarded as 'Nationally Critical' (*T. childella* and *T. hinewai*), three species are regarded as 'Nationally Endangered' (*E. banksiensis, N. vulcanus,* and *Z. wardi*), and four species are classified as 'Nationally Vulnerable' (*C. peninsulae, H. styx, O. banksiana,* and *Zelandoperla* sp. 1) (Grainger et al., 2018). *N. chiltoni* is not included in the assessment by Grainger et al. (2018). However, *N. chiltoni* has been assessed by Andrew et al. (2012) who suggested the taxa is 'Naturally Uncommon' (Grainger et al., 2014). Furthermore, *E. banksiensis, N. chiltoni, O. banksiana,* and both *Tiphobiosis* spp. have been recognised as species of interest to the Department of Conservation for a number of years (Collier, 1992).

Despite Banks Peninsula's stream invertebrates being highly threatened and recognised as species of conservation interest, little research has been carried out into their distribution and habitat preferences. *C. peninsulae* is the only *Costachorema* species found on the Peninsula and has been collected widely across the region (Ward, 1995, Smith, 2002). *C. peninsulae* is known to favour small to medium forested streams from sea level to 475 m a.s.l. (Ward, 1995, Smith, 2002, Harding, 2003). *C. peninsulae* was rarely collected by Harding (2003) suggesting the species occurs at low abundances. Similarly, very little is known about the distribution and ecology of *E. banksiensis* other than the specie's association with forested streams (Harding, 2003). There is some evidence that *E. banksiensis* may have also once occurred in the Nelson area, but the species has not been found there for some time and is now considered to be confined to Banks Peninsula (Collier et al., 2000). *H. styx* was first collected and described by McFarlane (1951) from the Styx River, Christchurch. *H. styx* has not been found in the Styx River since, despite being resampled multiple times (Harding, 2003). Styx River was previously a forested spring but is now an urban system. It is likely that habitat change caused the species extinction from the Canterbury Plains (Harding, 2003). *H. styx* is now restricted to Banks Peninsula and is considered to be regionally endemic (Harding, 2003). *H. styx* seems to be restricted to forested streams on Banks Peninsula, further supporting idea that indigenous forest loss in Christchurch resulted in the species extinction from the Styx River (Harding, 2003). The mayfly, *N. vulcanus* has been recorded east of Lyttelton Harbour in permanent streams from seal level to 500 m a.s.l. (Hitchings and Staniczek, 2003). Mature *N. vulcanus* larvae often gather in slow flowing water under vegetation before emerging (Hitchings and Staniczek, 2003).

The blephariceridae *N. chiltoni* is the only freshwater invertebrate to be extensively studied on the Peninsula. In the 1960's *N. chiltoni* were well distributed across Banks Peninsula, occurring in streams from just above sea level to around 335 m (Craig, 1969). *N. chiltoni* were known to be particularly abundant in the Peninsula's east and present in almost all streams where the flow was sufficient enough to keep rocks clear of algal growth in water velocities between 0.3 to 1.2 ms^{-1} (Craig, 1969, Collier, 1992). *N. chiltoni* are possibly the only endemic freshwater species on the Peninsula that is widely distributed and abundant in forested, partly forested, and open agricultural streams (Craig, 1969, Harding, 2003).

Little is known about the distribution and ecology of the beetle *O. banksiana.* The beetle was only collected from one stream in the Peninsula's southwest for formal description in 1973 (Ordish, 1984). However, the New Zealand Hydraenidae family is frequently found in headwater areas and is presumed to have evolved in forested streams (Ordish, 1984). This family of beetles are commonly collected under stones in rapids, amongst leaf litter, and are abundant in moss along the splash zone in streams (Ordish, 1984, R. Leschen, personal communication, 2019).

Information on both *T. childella* and *T. hinewai* is the most limited of the regionally endemic stream invertebrates. Both species are currently restricted to a single catchment (Hinewai Reserve of the Maurice White Native Forest Trust) (Ward, 1995). *T. childella* are known to occur in first order forested streams, while *T. hinewai* seems to occur in steep gradient forested streams (Ward, 1995). Personal communication with J. Harding and B. Smith (2019) suggests that these species favour seepage habitats adjacent to the main flows of headwater streams. Lastly, little is known about the distribution of *Z. wardi* beyond the study of Harding (2003), where the species was restricted to forested headwaters and occurred at low abundances. It appears that the speciation of *Z. wardi* is similar to *N. chiltoni* and the undescribed *Zelandoperla* species*.* These species diverged from alpine sister species during the during the Pleistocene around 10 Ma (Craig, 1969, McLellan, 1993, McLellan, 2006). Given that only a few hundred years ago the majority of Banks Peninsula was completely forested it is extremely likely that these regionally endemic stream invertebrates are adapted to forested stream environments.

2.1.3 Banks Ecological Districts

Nicholls (1979) first developed the concept of Ecological Districts, which subdivides each of New Zealand's ecoregions based on topography, geology, soil type, human impacts, and the distribution patterns of terrestrial flora and fauna (Nicholls, 1979). The Banks Ecological Region has been divided into three terrestrial Ecological Districts; Port Hills, Herbert, and Akaroa (Table 2.1) (Wassilieff and Timmins, 1984, Wilson, 1992, Wilson, 2013b). The Akaroa District is strongly influenced by the Pacific Ocean climate and currents (Wilson, 1992, Wilson, 2013b). The Herbert District has sub-alpine areas and cooler conditions, while the Port Hills District is drier and warmer than the rest of the Peninsula (Wilson, 1992, Wilson, 2013b). Some regionally endemic species are restricted to certain districts, such as the Akaroa daisy (*Celmisia mackaui*), which is only found in the Akaroa District (Wilson, 2013b). But other endemic plants and insects are distributed more widely across the Peninsula (e.g. *Veronica strictissima, Hemideina ricta,* and *Mecodema howitti*) (TownsendBrown et al., 1997, Anderson et al., 2003, Wilson, 2013b).

Table 2.1: Summary of the Ecological District classification and the three Ecological Districts on Banks Peninsula.

Ecological Districts (Nicholls, 1979)	
Definition: A local part of New Zealand that produces a characteristic landscape and range of biological communities, which are similar to other districts within a larger ecoregion (McEwen, 1987). Developed by Nicholls (1979) Districts are defined by five landscape processes proposed by Nicholls (1979): - Topography - Geology - Soil type - Vegetation - Human induced modifications	**Ecological Districts on Banks Peninsula:** Port Hills District: The smallest of the three Ecological Districts in the Banks Ecoregion. This north-eastern district is drier and warmer than the rest of the Peninsula. Herbert District: Land in the central area of the Banks Peninsula with sub-alpine areas and cooler conditions. Akaroa District: The eastward area of the Peninsula, surrounding Akaroa Harbour. This district is strongly influenced by the Pacific Ocean climate and currents.

2.1.4 The River Environment Classification and Freshwater Ecosystems of New Zealand

The River Environment Classification (REC) (Snelder and Biggs, 2002) and Freshwater Ecosystems of New Zealand (FWENZ) (Snelder et al., 2005) are two multivariate river classifications developed for national, regional, and local spatial analysis of New Zealand's river network. Both classifications were developed to aid environmental monitoring and guide the management of rivers and streams in New Zealand.

The REC assumes that biological distributions are dependent on landscape scale processes (Snelder and Biggs, 2002). The REC uses six hierarchical landscape categories to classify river reaches (Table 2.2). In descending order the REC categories are; watershed climate, source of flow, geology, land cover, network position, and valley landform (Table 2.2) (Snelder et al., 2010). The REC was originally developed from the ecoregion concept, to help guide the development of FWENZ. FWENZ is a numerical classification, which uses more than 25 proximal physical and chemical variables to classify the biological patterns of New Zealand's rivers using numeric clustering procedures (Table 2.3) (Leathwick et al., 2008, Leathwick et al., 2010). FWENZ assumes that biological distributions depend on variables such as nitrogen concentration, flow variability, distance to coast, average segment slope, and average riparian shading (Leathwick et al., 2010). FWENZ was the first numeric stream classification to be defined in New Zealand and was developed to implement the New Zealand Biodiversity Strategy (Snelder et al., 2005). Both classifications are used to explain the variation in freshwater communities, predict the occurrences of freshwater fauna, and guide conservation in New Zealand. These classifications are commonly used by Regional Councils and the Department of Conservation.

Table 2.2: Summary of the River Environment Classification and the different river environments surveyed on Banks Peninsula over the summer of 2018/19 for stream invertebrates.

River Environment Classification (Snelder and Biggs, 2002)	
Definition: The River Environment Classification uses six hierarchical landscape categories to classify New Zealand's river network into different environments at a river segment resolution. Developed by Snelder and Biggs (2002) Resolution increases as more of the six landscape characters are included The River Environment Classification is defined by six physical landscape characters of New Zealand's rivers, which are assigned hierarchically. The following flow diagram shows the six landscape variables and the categories of each of the landscape variable present on Banks Peninsula: **1. Watershed climate** *(Landscape variable)* ↓ Cold Dry (CD) (*Landscape categories)* Cold Wet (CD) **2. Source of flow** ↓ Hill (H) Low Elevation (L) **3. Geology** ↓ Volcanic Basic (VB) Miscellaneous (M) **4. Land cover** ↓ Pastural (P) Scrub (S) **5. Network position** ↓ Low Order (LO) Medium Order (MO) **6. Valley landform** High Gradient (HG) Medium Gradient (MG) Low Gradient (LG)	**River environments surveyed on Banks Peninsula:** ***Cold Dry Climate Environments:*** CD/H/VB/P/LO/HG: Steep, small (1^{st} or 2^{nd} order) streams flowing from hills through pastural land and volcanic basic rock. CD/L/VB/P/LO/HG: Steep, small (1^{st} or 2^{nd} order) streams, sourced from low elevation land and pastural vegetation with volcanic basic rock. CD/L/VB/P/MO/MG: Moderate gradient, medium sized (3^{rd} or 4^{th} order) streams, sourced from low elevation land and pastural vegetation with volcanic basic rock. Other Cold Dry Environments (grouped for analysis): CD/L/M/P/LO/HG CD/L/VB/P/LO/MG CD/L/VB/P/MO/HG CD/L/VB/P/MO/LG ***Cold Wet Climate Environments:*** CW/H/VB/P/LO/HG: Steep, small (1^{st} or 2^{nd} order) streams with volcanic basic rock, sourced from hills and with pastural vegetation. CW/H/VB/P/MO/HG: Steep, medium sized (3^{rd} or 4^{th} order) streams with volcanic basic rock, sourced from hills and with pastural vegetation. CW/L/VB/P/LO/HG: Steep, small (1^{st} or 2^{nd} order) streams with volcanic basic rock, sourced from low elevation land and with pastural vegetation. CW/L/VB/P/MO/MG: Moderate gradient, medium sized (3^{rd} or 4^{th} order) streams with volcanic basic rock, sourced from low elevation land and with pastural vegetation. Other Cold Wet Environments (grouped for analysis): CW/H/VB/P/MO/MG CW/H/VB/S/LO/HG CW/H/VB/S/MO/HG CW/L/M/P/LO/HG CW/L/VB/P/LO/MG CW/L/VB/P/MO/HG

Table 2.3: Summary of the multivariate classification Freshwater Ecosystems of New Zealand and the different river ecosystems surveyed on Banks Peninsula over the summer of 2018/19 for stream invertebrates.

Freshwater Ecosystems of New Zealand (Snelder et al., 2005)	
Definition: Freshwater Ecosystems of New Zealand is a numerical classification, which uses more than 25 proximal physical and chemical variables to classify the biological patterns of New Zealand's rivers using numeric clustering procedures (Leathwick et al., 2008, Leathwick et al., 2010). Classifies New Zealand's river network into different ecosystems at a river segment resolution. Developed by Snelder et al. (2005) Has four levels of resolution: 20 level, 100 level, 200 level, and 300 level Examples of the variables used to define different river ecosystems: - Nitrogen concentration - Flow variability - Distance to coast - Average segment slope - Average riparian shading	**Freshwater Ecosystems surveyed on Banks Peninsula at a 300 level** C1.1b: Very steep gradient, high altitude streams in the headwaters of larger valleys, which are very small. Streams have high levels of riparian shading, coarse gravel substrates, a mild maritime climate, and are dominated by riffle flow types. C1.2a: Occurs from the headwaters to the coast across the Peninsula. These stream ecosystems are very steep, have high levels of riparian shading, coarse gravel substrates, a mild maritime climate, and are dominated by riffle flow types. C5.2c: These small stream ecosystems have high levels of riparian shading, coarse gravel substrates, and a mild maritime climate. Additionally, these streams have moderate gradients and a gentle down stream flow. C8.1a: Is an inland ecosystem. On the Peninsula this ecosystem consists of small (1st and 2nd order) streams, dominated by gravely substrates, and riffle flow types. Other ecosystems (grouped for analysis): C1.1c - very small short 1st order streams that occur in maritime climates C6.4a - Larger (3rd and 4th order) streams in areas transitioning from maritime to inland climates C6.4b - Larger (3rd and 4th order) streams in areas transitioning from maritime to inland climates C8.3a - Small inland streams that occur at the top of catchments in the Peninsula's west. C8.6a - Larger streams (2nd and 3rd order) in the Peninsula's west and are commonly sourced from C8.1a and C8.3a inland ecosystems.

2.1.5 Study objectives and aims

Understanding the spatial distribution of species is critical for their protection and conservation. However, it is challenging to determine the distribution of an entire insect species. One approach, which has not been tested with endemic stream invertebrates is to determine if classification systems such as Ecological Districts (Nicholls, 1979), River Environment Classification (Snelder and Biggs, 2002), and Freshwater Ecosystems of New Zealand (Snelder et al., 2005) have the potential to provide insight into species distributions.

A survey of benthic stream invertebrates from 54 streams across Banks Peninsula was carried out to address the following aims:

1. *Determine the distribution of Banks Peninsula's regionally endemic stream invertebrate species.*

2. *Examine whether the Ecological Districts, REC, or FWENZ classifications explain the spatial variation of Banks Peninsula's endemic stream invertebrates.*
3. *Identify the key habitat and environmental variables that are associated with the occurrences of Banks Peninsula's regionally endemic stream invertebrates and whether these variables help to explain the species associations with the multivariate classifications.*

I hypothesised that the majority of the endemic species would be associated with the Ecological Districts, river environments, and ecosystems with higher native forest cover. A major outcome of this study was to increase the understanding of Banks Peninsula's rare stream invertebrates.

2.2 METHODS

2.2.1 Field survey

2.2.1a Invertebrate collection

A total of 54 1st to 4th order rivers and tributary streams were surveyed across Canterbury's Banks Peninsula, between December 2018 and February 2019. Streams were selected to provide spatial coverage of the entire Peninsula, including small headwater streams and larger lowland rivers. Each stream surveyed was chosen to encompass a range of land cover from established old growth podocarp forest to regenerating native scrub and open pastural land. The streams surveyed were located on public land, public conservation land, privately protected covenant areas, and private land. In total 10 1st order, 20 2nd order, 22 3rd order, and two 4th order streams were surveyed. Stream order was defined using the 'top down' method of Strahler (1957) based on the NZ River Centre Lines produced by Land Information New Zealand (2019b).

Within each stream a sampling reach of 10-15 m long was identified. Sampling reaches were chosen to include typical terrestrial vegetation in that stream reach and where possible a riffle, run, pool, and organic matter microhabitats. At each reach benthic invertebrate samples were collected using a kick-net (250 µm mesh). Kick netting (as opposed to other methods) was used to ensure a range of habitats could be sampled efficiently in varying water depths, velocities, and amongst variable organic matter and substrate sizes. Many of the Peninsula's streams are dominated by large boulders making Surber samplers ineffective. Thus, kick netting increased the chance of collecting a larger range of taxa. When possible, at each sampling reach four separate invertebrate samples were collected from a riffle, run, pool, and organic matter microhabitats. Organic matter invertebrate samples were collected amongst leaf litter, macrophytes, moss, and submerged woody debris. To ensure consistency was maintained between streams and macrohabitat samples, all 202 kick net samples were collected by myself. Each specific microhabitat invertebrate sample was kept separate and preserved in 70 % ethanol.

2.2.1b Habitat survey

At each of the 54 streams habitat information was collected on instream and riparian conditions. GPS and altitude measurements were recorded using a GARMIN eTREAK 10 at each survey stream. At each reach bank and bed stability was assessed using the Channel Stability Index (Pfankuch, 1975). This method sums the scores of 15 environmental variables over the sampled reach area. In-stream particle size was measured using the Substrate Index method of Jowett and Richardson (1990) modified to the Wentworth Scale for partial size classification by Harding et al. (2009). This consisted of randomly selecting 30 stream bed particles from each reach and measuring their intermediate axis. The Substrate Index for each stream was then calculated using the following formula:

Substrate Index (SI) = 0.08 % bedrock + 0.07 % boulder + 0.06 % cobble + 0.05 % pebble
+ 0.04 % gravel + 0.03 % gravel & silt

Stream shading for each stream reach was determined using a spherical densiometer (model A convex). Four shade measurements were taken facing each direction and the average taken to give the final proportion of shade cover over the stream following the methods of Lemmon (1956) and Lemmon (1957). Shade cover estimations include cover provided by vegetation, stream banks, and hill slopes. Riparian cover was visually estimated and classed into 10 categories (mature podocarps, regenerating native vegetation, exotic trees, exotic grass, gorse and broom, tussock, ferns, wetland vegetation, soil, and rock). The average was taken of each riparian cover type across both banks of the surveyed river reach to give the final riparian cover percentages. Podocarps, regenerating native vegetation, ferns, tussock, and wetlands were considered as native riparian vegetation cover. Following the methods outlined by Harding et al. (2009), velocity (ms^{-1}) over a 10 second period was determined at four-tenths of the water depth from the surface in each microhabitat environment (riffle, run, and pool) using a Marsh-McBierney Model 2000 Flo-Mate. The average of these readings was then used to give a final stream velocity value. Stream depth (m) was measured in each microhabitat (riffle, run, and pool) where velocity was recorded and then averaged to give a final value. Stream width (m) was measured at each survey reach in a stream section that was representative of the reach. Spot water chemistry measurements are not included in this chapter but are included in Chapter three.

2.2.2 Laboratory methods

In the laboratory macroinvertebrate samples were rinsed with water through a 250 μm sieve. Individuals were then identified and counted using a binocular stereomicroscope at 10-63 x magnification. The following seven regionally endemic stream invertebrates were described to a species level based on the following descriptions:

- *C. peninsulae* was identified using Smith (2001) and Smith (2002).
- *H. styx* was identified using Smith (2001).
- *N. chiltoni* was identified using Winterbourn et al. (2006).
- *N. vulcanus* was identified using Hitchings and Staniczek (2003) and Winterbourn et al. (2006).
- *O. banksiana* was identified to a genus level using Winterbourn et al. (2006) and to a species level by Dr Richard Leschen of Landcare Research in Auckland, to the description of Delgado and Palma (1999) based off the original speciation by Ordish (1984).
- *Z. wardi* was identified using McLellan (1993) and personal communication with J. Harding (2019).
- *Zelandoperla* sp. 1 (BJF00160; Banks Peninsula) was confirmed to be the undescribed stonefly species of clade 5 described by McCulloch et al. (2009) through genetic analysis carried out by the Zoology Department at the University of Otago (B. Foster, personal communication, 2019). See Appendix 1 for further detail.

Images of these seven endemic species are shown in Appendix 2. Other endemic species including both *Tiphobiosis* species and *E. banksiensis*, were either not collected or not collected frequently enough to be included in this chapter of my thesis. The total diversity and relative abundance of each species for each stream was determined by combining the respective microhabitat (riffle, run, pool, and organic) kick net results of each stream.

2.2.3 GIS data extraction and mapping

The boundary of the Banks Ecoregion is defined by the change in geology from Banks Peninsula's volcanic rock to the surrounding Quaternary deposits of the Canterbury Plains (Wilson, 1992, Harding and Winterbourn, 1997). Boundaries for the Ecological Districts were modelled off those outlined in Wilson (1992). Both the REC and FWENZ classifications were obtained from GIS layers for each segment (or NZReach number) associated with each of the streams surveyed. All six hierarchical categories of the REC were used to define the different river environments surveyed on Banks Peninsula. FWENZ categories were defined to a 300-class level. The 54 streams fell into 17 different REC environments and nine different 300 level FWENZ categories (Table 2.2 and 2.3). The highest resolution levels of both the REC and FWENZ were used as this study is focused on a single small ecoregion.

Vegetation data used for mapping was extracted from the LINZ (Land Information New Zealand) data service from two data layers (NZ Native Polygon (Topo, 1:50k) and NZ Scrub Polygon (Topo, 1:50k)) (Land Information New Zealand, 2019a, Land Information New Zealand, 2019c). Both vegetation layers used were updated in July 2019 and are at a 1:50,000 scale. The native polygon layer represents land covered by trees native to New Zealand, while the scrub layer represents vegetation < 3 m high with continuous cover (Scrub Polygon) (Land

Information New Zealand, 2019a, Land Information New Zealand, 2019c). Both vegetation layers were used, apposed just to native tree cover as the scrub layer captures young regenerating native vegetation such as kānuka.

2.2.4 Analysis

All six hierarchical categories of the REC were used in analysis. However, rarely sampled (< 3 sampling locations) REC environments were grouped into two categories, cold wet and cold dry (Table 2.2). Rarely sampled 300 level FEWNZ ecosystems (C1.1c, C6.4a, C6.4b, C8.3a, and C8.6a) were all grouped into a single class for analysis by their 20 FWENZ level class (Table 2.3). These five stream ecosystems were grouped because they share similarities such as low discharge (< 0.9 cumecs), unstable flows, and generally have coarse gravel substrates (Table 2.3) (Leathwick et al., 2008). These ecosystems and environments were grouped because statistical analysis could not be ecologically interpreted when there were only one or two sampled streams from these environments and ecosystems. These environments and ecosystems only occurred in very limited areas of the Peninsula. For example, the environment CW/H/VB/S/LO/HG only occurred in a single stream reach on the Peninsula. By grouping these infrequently sampled environments and ecosystems, the 17 REC classifications were reduced to nine and the nine FWENZ 300 level ecosystems were reduced to five (Tables 2.2 and 2.3). At the 200 FWENZ level two uncommon ecosystems (C8.3 and C8.6) were combined for analysis.

Poisson generalised linear models (GLM) were used to determine whether there was a relationship between the number of different endemic species present and the different Ecological Districts, REC environments, and FWENZ ecosystems at 300, 200, and 100 levels. All FWENZ (100, 200, and 300 levels) models were over dispersed and accounted for by using a Quasi-Poisson model and F-test, opposed to a standard Poisson model and Chi squared test. Binomial generalised linear models were used to determine if the proportion of occurrence of each endemic species differed significantly between the three Ecological Districts, the nine REC classifications, and five FWENZ 300 levels. All statistical analysis was performed using RStudio Version 1.1.447 (RStudio Team, 2016).

A constrained correspondence analysis (CCA) was carried out to determine the influence of environmental variables on the community structure of the streams where endemic species were collected (n = 47) using the community ecology R package Vegan Version 2.5-6 (Oksanen et al., 2019). Endemic species were not collected from seven streams (stream codes: 1-TW, 2-TW, 5-L, 6-L, 41-OBN, 53-OBE, and 54-OBE), which were removed from the CCA and accompanying analysis. The CCA was scaled using Hill's Scaling, which rescales of the axis scores to improve ecological interpretation. Analysis of variance (ANOVA) permutation was performed to determine if there was a linear relationship between the endemic invertebrate communities and the environmental variables. Lastly, an ANOVA permutation using Type III sums of squares (significances of marginal effects) was used to determine the significance of the relationship between each environmental variable and the community. Eight environmental variables (channel instability, stream shading, native riparian vegetation cover, stream velocity, stream depth, stream width, altitude, and substrate) were included in the model. Both stream shading and the proportion of native riparian vegetation have been used in the model, as there was a number of streams with high shading from exotic vegetation or bank cover. No chemical variables were used in this model.

2.3 RESULTS

2.3.1 Endemic species distributions

Endemic species where found at 87 % of the streams surveyed (Fig. 2.1). Seven of the 10 regionally endemic species were commonly collected across the Peninsula. These endemic species were *C. peninsulae, H. styx, N. chiltoni, N. vulcanus, O. banksiana, Z. wardi,* and *Zelandoperla* sp. 1. All seven endemic species were found to co-occur together in three stream reaches. These streams were in the headwaters of the Kaituna Valley (12-TW) and near Akaroa township (39-A and 44-A) (Fig. 2.1). In general streams near the coast and in the northern area of the Peninsula had fewer endemic species, while endemic co-occurrence was high around the central area of the Peninsula and Akaroa Harbour (Fig. 2.1).

The beetle *O. banksiana* was the most common species, occurring at 67 % of the streams surveyed, with a mean abundance of 7 ± SE 1.3 individuals per stream (Fig. 2.2e). *O. banksiana* were found from 2 to 448 m a.s.l.. The net-winged midge, *N. chiltoni* occurred at 59 % of streams, making it the second most common endemic species on the Peninsula (Fig. 2.2c). *N. chiltoni* occurred from 2-296 m a.s.l. and were the most abundant endemic species. They were frequently collected at abundances > 50, but on average 18 ± SE 5.2 individuals were collected per stream. Both *O. banksiana* and *N. chiltoni* were absent northwest of Lyttelton Harbour but were collected east of the Harbour (Fig. 2.2 c and e). *N. vulcanus* was the third most common endemic, occurring at 48 % of streams with an average abundance of 5 ± SE 1.4 individuals per stream (Fig. 2.2d). were absent from much of the western and northern areas of the Peninsula. Abundances of *N. vulcanus* were greater in the south and south-eastern areas of the Peninsula, where they were collected from 83 to 448 m a.s.l..

Z. wardi was found at 41 % of streams at low abundances (3 ± SE 1.1 per stream). *Z. wardi* were collected from 50 to 448 m a.s.l.. With the exception of two streams, *Z. wardi* was found only in headwaters (Fig. 2.2f). The occurrence of the *Z. wardi* in the Port Hills the is the most eastern limit of any of the endemic species (Fig. 2.2f). Both of the caddisfly species (*C. peninsulae* and *H. styx*) were found at 39 % of streams (Fig. 2.2 a and b). However, *C. peninsula* has a lower mean abundance per stream (1 ± SE 0.2) compared to *H. styx* (2 ± SE 0.4). Both caddisflies were collected from similar elevation ranges of 30-448 and 42-448 m a.s.l., respectively. *Zelandoperla* sp. 1 had the most restricted distribution of all the endemic species assessed in this study (Fig. 2.2g). The stonefly only occurred at 20 % of the streams surveyed and on average only 1 ± SE 0.3 *Zelandoperla* sp. 1 was collected per stream. The stonefly was mostly found at low abundances (< 5 individuals), with the exception of two streams, where 15 and 8 individuals were collected. The species was only collected from high elevations between 83-448 m a.s.l..

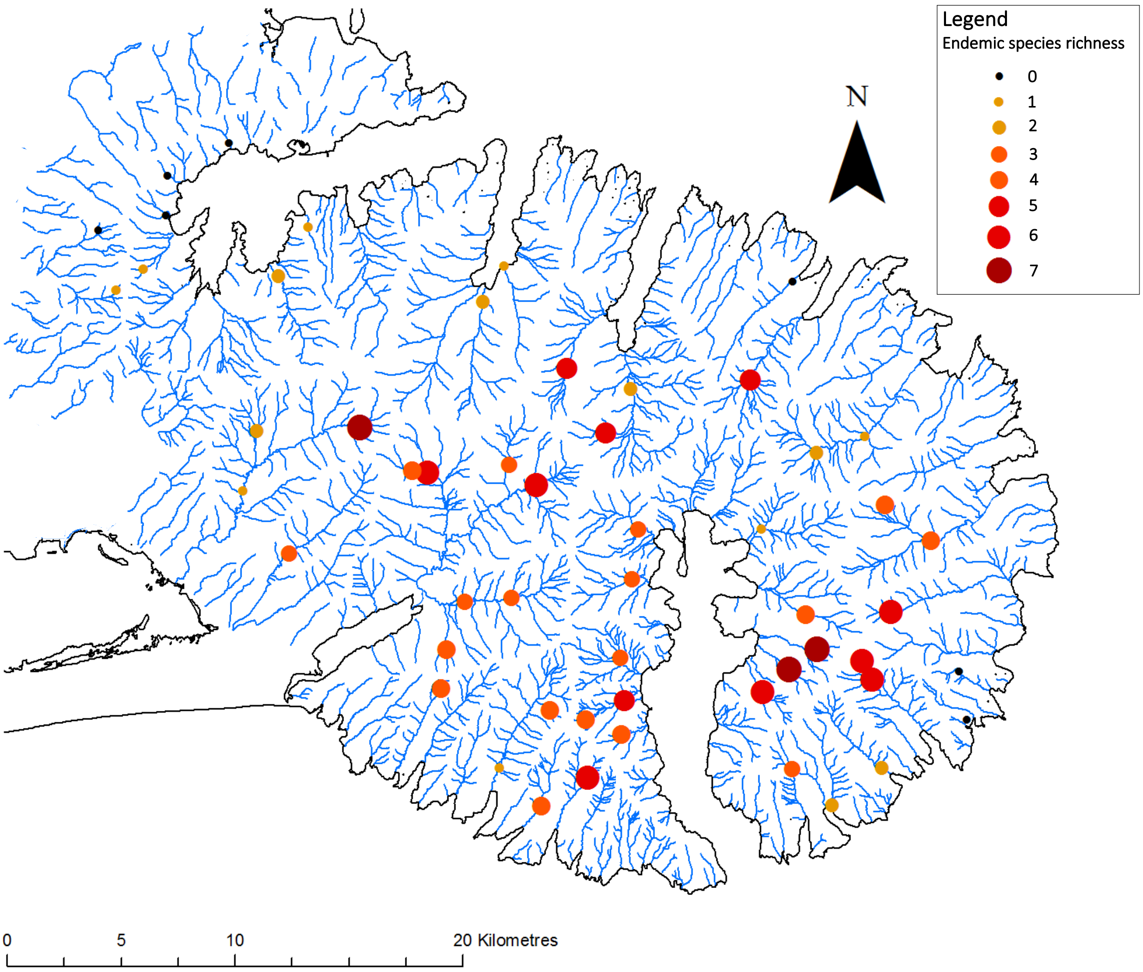


Figure 2.1: Regionally endemic stream invertebrate richness across on Banks Peninsula. Point size increases and reddens with increasing endemic species richness. Black points represent streams where endemic species were not collected. Seven endemic species (*C. peninsulae, H. styx, N. chiltoni, N. vulcanus, O. banksiana, Z. wardi,* and *Zelandoperla* sp. 1) were sampled for at 54 streams on Banks Peninsula in the 2018/19 summer.

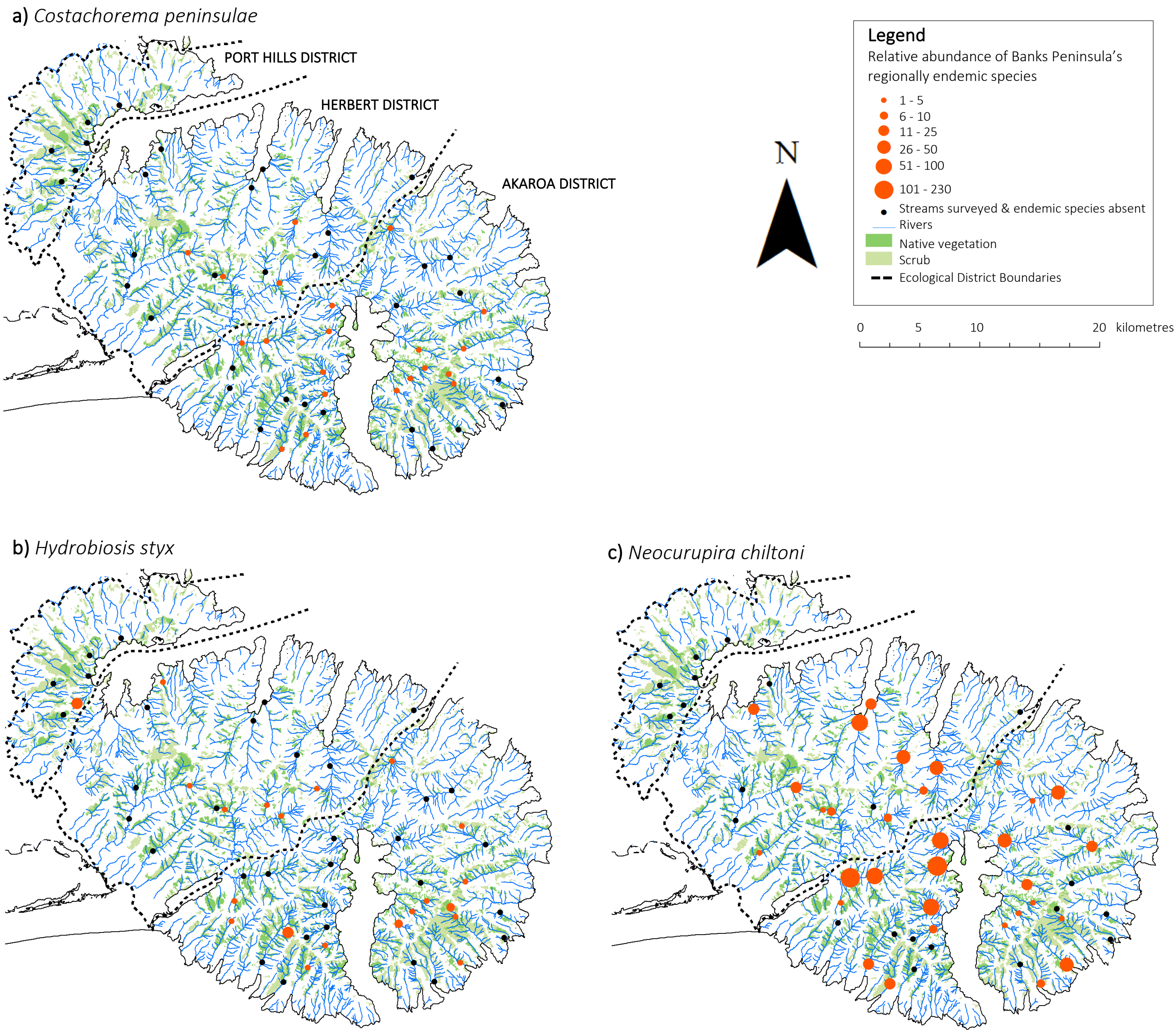


Figure 2.2: Ecological Districts of Banks Peninsula and the associated distributions of seven regionally endemic stream invertebrates collected from a survey of 54 streams carried out over the 2018/19 summer. Orange data points represent streams where the specie's was collected and their relative abundance at the stream. Black data points represent streams reaches where the specie's was not collected. Green areas indicate areas of regenerating and old growth native tree cover, and scrub vegetation less than three metres tall.

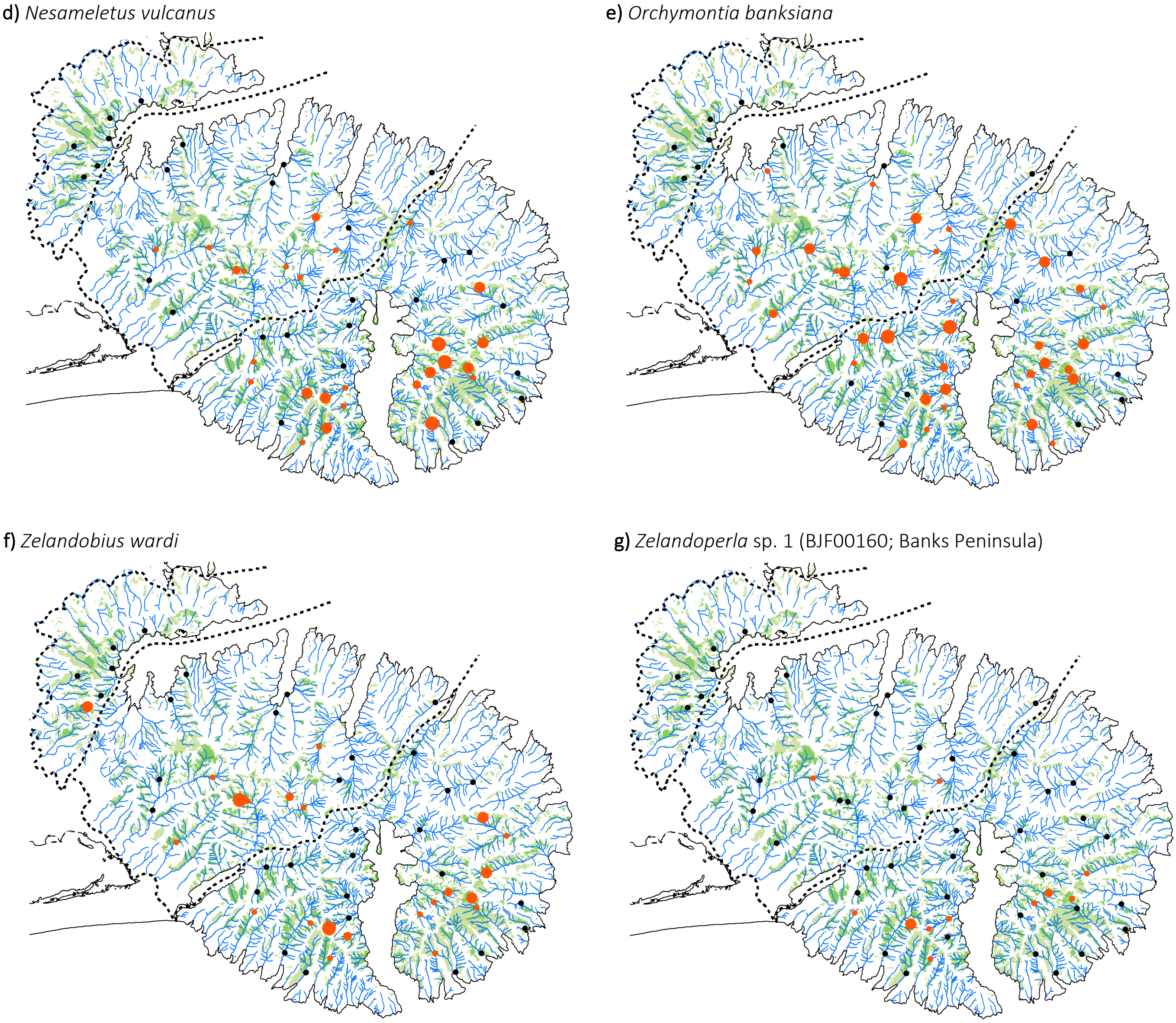


Figure 2.2 continued

2.3.2 Ecological Districts

There was a significant (χ^2=26.6, df=2, 52, p<0.001) difference between the number of endemic species present across the three Ecological Districts. All seven of the endemic species were collected from both the Akaroa and Herbert Ecological Districts (Fig. 2.2). Only two endemics (*H. styx* and *Z. wardi*) were collected from the Port Hills Ecological District (Fig. 2.2). Both *H. styx* and *Z. wardi* were only found at one stream each in the Port Hills

District. The proportion of occurrences of *C. peninsulae, N. chiltoni, N. vulcanus,* and *O. banksiana* were found to differ significantly between the Ecological Districts (Table 2.4). While, the occurrences of *H. styx, Z. wardi*, and *Zelandoperla* sp. 1 did not differ between the three Ecological Districts (Table 2.4).

Table 2.4: Binomial generalised linear model results for each endemic species and the environmental classifications (Ecological Districts, River Environment Classification (REC), and Freshwater Ecosystems of New Zealand (FWENZ)). Nine different REC environments were used in this analysis based off all six landscape categories used to define the REC. FWENZ is based off the five ecosystems recognised at a 300 level. Uncommon (occurring at less than three sampled streams) REC environments and FWENZ ecosystems have been combined into two groups (Cool Dry and Cool Wet for REC) and one group for FWENZ.

	Ecological Districts df = 2, 51		**REC** df = 8, 45		**FWENZ** df = 4, 49	
	χ^2	p-value	χ^2	p-value	χ^2	p-value
Costachorema peninsulae	7.63	**<0.05**	15.20	0.06	3.26	0.52
Hydrobiosis styx	1.64	0.44	21.60	**<0.01**	2.55	0.64
Neocurupira chiltoni	11.95	**<0.01**	26.47	**<0.001**	21.99	**<0.001**
Nesameletus vulcanus	8.58	**<0.05**	39.87	**<0.001**	3.90	0.42
Orchymontia banksiana	14.80	**<0.001**	15.08	0.06	7.06	0.13
Zelandobius wardi	1.84	0.40	33.33	**<0.001**	0.75	0.95
Zelandoperla sp. 1(BJF00160; Banks Peninsula)	3.53	0.17	23.54	**<0.01**	6.36	0.17

2.3.3 River Environment Classification

The 54 streams surveyed were classified into 17 REC classes consisting of two climate, two source of flow, two geology, two land cover, three network position, and three valley landform categories (Table 2.2). However, five cold wet climate streams and three cold dry climate stream environments were grouped as they were surveyed less than three times (Table 2.2). Thus, reducing the number of environments that were analysed to nine. There was little landscape variation in the REC of Peninsula's geology and land cover classes, which were dominated by volcanic basic rock and land cover and pasture, respectively.

In the central high-altitude area of the Peninsula steep gradient cold wet streams of low to medium order, sourced from hills dominate (e.g. CW/H/VB/P/MO/HG and CW/H/VB/P/LO/HG). Streams in cold wet climates at mid altitudes (e.g. CW/L/VB/P/MO/MG and CW/L/VB/P/LO/HG) also had similar environmental characters to cold wets climate headwater streams (Table 2.2). The five uncommonly sampled cold wet climate stream environments were a mix of orders, gradients, and flow sources. These environments only occurred in few streams on the Peninsula (Table 2.2). Low order, high gradient streams sourced from lower elevations dominated areas on the Peninsula in cold dry climates (e.g. CD/L/VB/P/LO/HG). These streams are most common in the Port Hills area, in small catchments close to the ocean, and in tributary streams that joined larger streams near the coast. Cold dry climate tributary streams (CD/H/VB/P/LO/HG) just outside of the main rainfall areas on the Peninsula were also common, particularly in the south. All medium order streams in cold dry environments were restricted to lowland areas at the base of large catchments, such as the Kaituna River and Opara Stream. The remaining three uncommonly sampled cold dry climate stream environments were all sourced from low elevations and were a mixture of low gradients and orders (Table 2.2).

There was a significant (χ^2=44.6, df=8, 45, p<0.001) difference between the number of endemic species present and the nine different river environments surveyed on the Peninsula. The river environments CW/H/VB/P/MO/HG and CW/H/VB/P/LO/HG had the highest number of endemic invertebrates with means of 6 (± SE 0.4) and 5 (± SE 0.5), respectively. The three streams where all seven endemic species co-occurred were sourced from hills, had volcanic-basic geology, pastural land cover, and high gradient valley landforms. These environments were CD/H/VB/P/LO/HG, CW/H/VB/P/LO/HG, and CW/H/VB/P/MO/HG. The seven streams where no endemic species occurred classified into three river environments (CD/L/VB/P/LO/HG, CD/L/VB/P/LO/MG and CW/L/M/P/LO/HG). All of these environments have low elevation flow sources, pastural land cover, and were low order streams.

None of the endemic species were collected from the same combination of river environments (Fig. 2.3). *C. peninsulae, N. chiltoni*, and *O. banksiana* were collected from the same main environments but were collected from differing combinations of the rarely sampled environments (Fig. 2.3 a, c, and d). *C. peninsulae* and *N. chiltoni* were found in small headwaters in wet climates and larger dry climate streams (Fig. 2.3 a and c). While, *O. banksiana* occurred in most river environments on the Peninsula, except for 1st and 2nd order streams with a low elevation source of flow (Fig. 2.3 d). *H. styx, N. vulcanus,* and *Z. wardi* were found in a similar range of river environments that covered a wide area of the Peninsula, from small headwater streams to small coastal streams (Fig. 2.3 b, d, and f). However, these three species were only collected once from the cold dry climate stream environment CD/H/VB/P/LO/HG, at the same stream near the southern entrance of Akaroa Harbour (stream 31-A). *Zelandoperla* sp. 1 were found to have the most restricted distribution of the endemic species based on the REC. *Zelandoperla* sp. 1 only occurred in four river environments, which are restricted to the central area of the Peninsula (Fig. 2.3 g). The stonefly was restricted to steep gradient streams that were mostly 1st and 2nd order streams in cold wet climates.

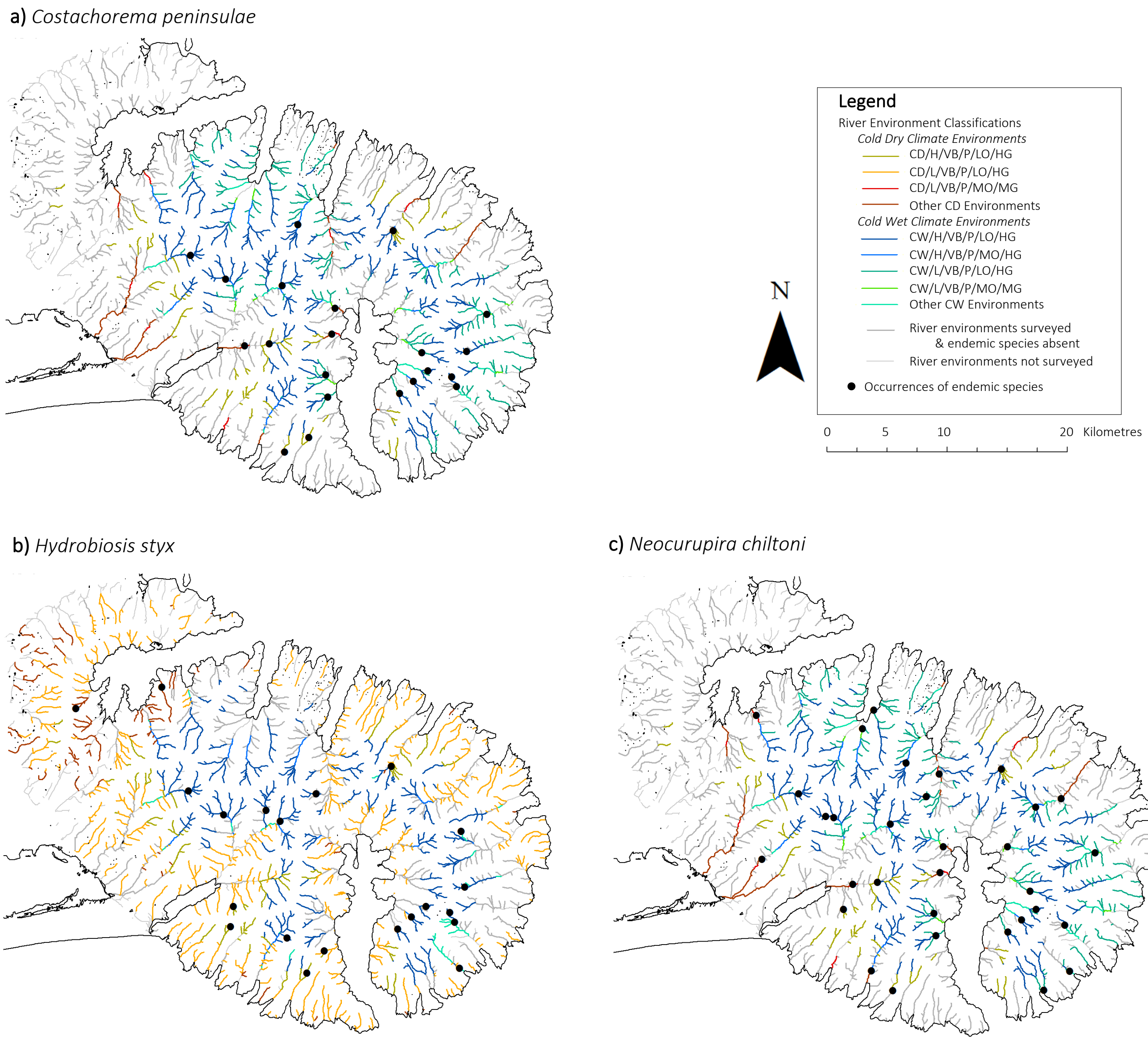


Figure 2.3: The spatial distribution of the River Environment Classifications (REC) of streams on Banks Peninsula where seven regionally endemic stream invertebrates were collected over the 2018/19 summer from a survey of 54 streams. Black data points indicate where each endemic species was collected. The six hierarchical REC categories are as follows: Climate is classed as cool dry (CD) or cool wet (CW), source of flow as hill (H) or low elevation (L), geology as volcanic basic (VB) or miscellaneous (M), land cover as pastural (P) or scrub (S), network position as low order (LO) or high order (HO), and valley landform as high gradient (HG), medium gradient (MG), and low gradient (LG). River environments sampled less than three times were grouped by climate type (cold dry or cold wet) as marked in the map legend.

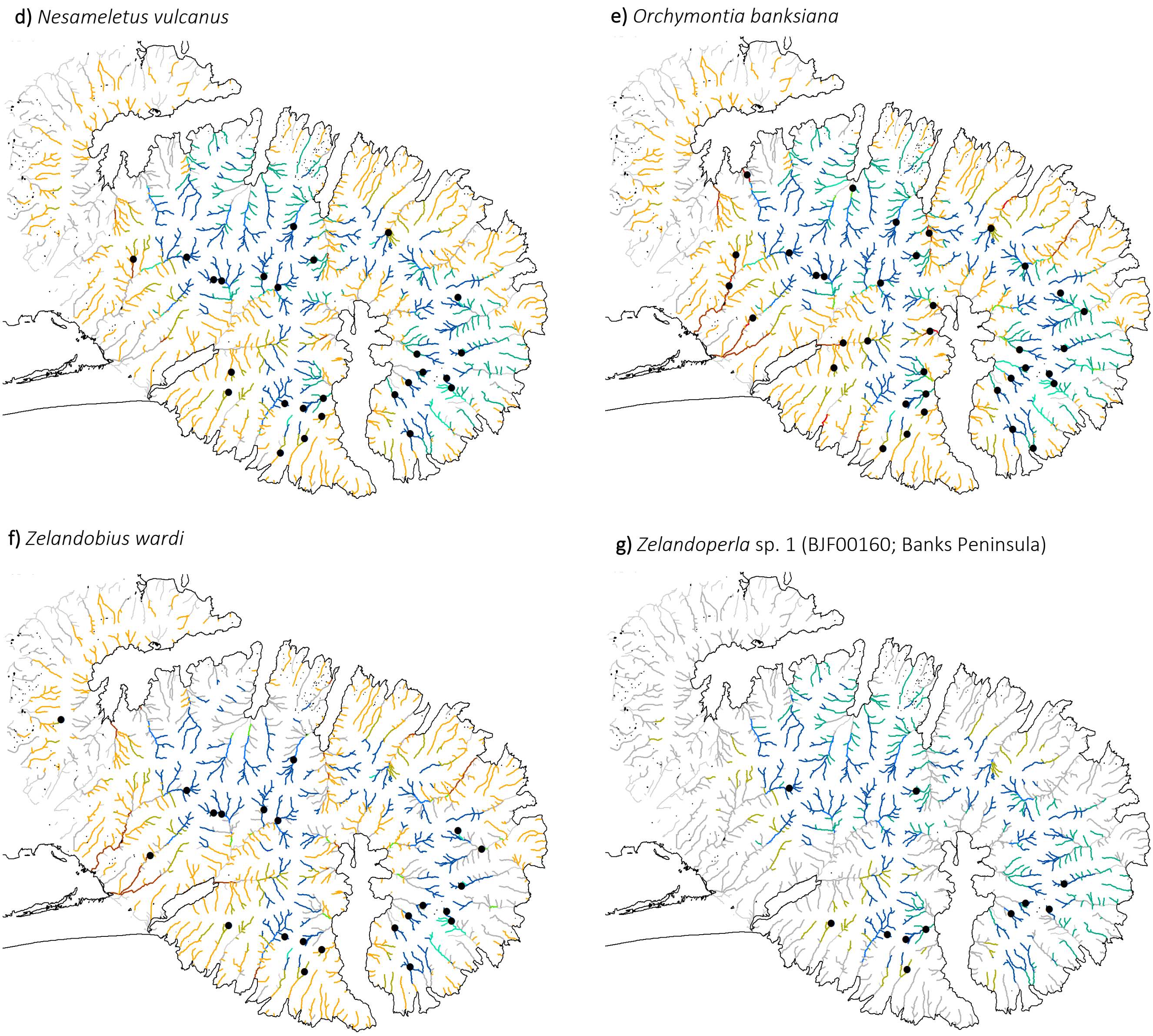


Figure 2.3 continued

The occurrences of *H. styx, N. chiltoni, N. vulcanus, Z. wardi,* and *Zelandoperla* sp. 1 differ significantly between the different river environment classifications (Table 2.4). All of these species were frequently collected in high gradient streams, sourced from hills in cold wet climates (CW/H/VB/P/LO/HG and CW/H/VB/P/MO/HG) and rarely or never collected in the environments CW/L/VB/P/LO/HG and CD/H/VB/P/LO/HG. Stream environments where two or less endemic species occurred were a mixture of cold wet and cold dry climates, but were all small 1st and 2nd order streams sourced from low elevations (e.g. CD/L/M/P/LO/HG, CD/L/VB/P/LO/MG, CW/L/M/P/LO/HG, and CW/L/VB/P/LO/MG).

2.3.4 Freshwater Ecosystems of New Zealand

A total of nine different ecosystems were surveyed across the Peninsula at the 300 level of FWENZ. All of the ecosystems recognised on the Peninsula are considered to have unstable low flows (Leathwick et al., 2008, Storey, 2012). Four ecosystems (C1.1b, C1.2a, C5.2c, and C8.1a) dominated the Peninsula (Table 2.3 and Fig. 2.4). Small maritime streams (C1 type) are found at some of highest densities in the country on Banks Peninsula (Storey, 2012). Both the C1.1b and C1.2a ecosystems consist of very small streams, with high levels of riparian shading, coarse gravel substrates, very steep gradients, and have mild maritime climates (Leathwick et al., 2008, Storey, 2012). C1.1b generally occurs at higher altitudes in headwaters of larger valleys on the Peninsula. While C1.2a occurs from the headwaters to the coast across the Peninsula. Riffle type environments dominate these steep C1 ecosystems (Storey, 2012). The ecosystem C5.2c is similar to the C1 streams, these small streams share high levels of riparian shading, coarse gravel substrates, and mild maritime climates (Table 2.3). However, C5.2c streams have moderate gradients and a gentle down stream flow. The ecosystem C8.1a only occurs in the Peninsula's west, because it is an inland ecosystem (Table 2.3 and Fig. 2.4). On the Peninsula C8.1a consists of small (1st and 2nd order) streams, dominated by gravely substrates, and riffle flow types (Storey, 2012). Riparian shading is considered to be moderate in this ecosystem (Leathwick et al., 2008). There were five other maritime climates ecosystems surveyed on the Peninsula (C1.1c, C6.4a, C6.4b, C8.3a, and C8.6a. C1.1c) that consists of very small short 1st order streams (Table 2.3). C6.4a and C6.4b occur in areas that are transiting from costal to inland ecosystems. They are larger (3rd to 4th order) gravely streams on the Peninsula with gentle flows and gradients. C8.3a and C8.6a are both inland ecosystems similar to C8.1a. The ecosystem C8.3a consists of small streams, which occur at the top of catchments in the Peninsula's west. C8.6a are larger streams (2nd and 3rd order) in the Peninsula's west and are commonly sourced from C8.1a and C8.3a streams.

The number of endemic species did not differ significantly ($F_{4,49}$=1.09, p=0.37) between the different freshwater environments at a 300 level. Additionally, no statistical difference was found between the number of endemic species present and the different freshwater environments at a 100 level ($F_{3,50}$=0.80, p=0.50) and at a 200 level ($F_{5,\ 48}$=1.09, p=0.38). The 300-level freshwater ecosystem C1.1b had the highest mean number of endemic species present at 4 (± SE 0.8). All seven endemic species occurred in three different ecosystems (C1.1b, C1.2a, and C8.1a). All three of these ecosystems consists of small steep shaded streams. The ecosystems C1.2a, C5.2c, and C8.1a contained streams were no endemic species were found.

N. chiltoni was the only endemic species to show a significant difference in occurrence across the different 300 level freshwater ecosystems (Table 2.4 and Fig. 2.4c). *H. styx, N. vulcanus,* and *Zelandoperla* sp. 1 were collected from the same five ecosystems; C1.1b, C1.1c, C1.2a, C5.2c, and C8.1a (Fig. 2.4 b, d, and g). *Z. wardi* were also collected from these five ecosystems and C8.3a and C8.6a (Fig. 2.4f). *C. peninsula* were collected from collected from C1.1b, C1.2a, C5.2c, C8.1a, and the larger stream ecosystem C6.4b (Fig. 2.4a). *N. chiltoni* and *O. banksiana* were collected from all of the ecosystems sampled on the Peninsula, except for the two uncommon very small stream ecosystems (C1.1c and C8.3a) (Fig. 2.4 c and e). Additionally, *O. banksiana* were collected from the larger inland ecosystem C6.4a.

a) *Costachorema peninsulae*

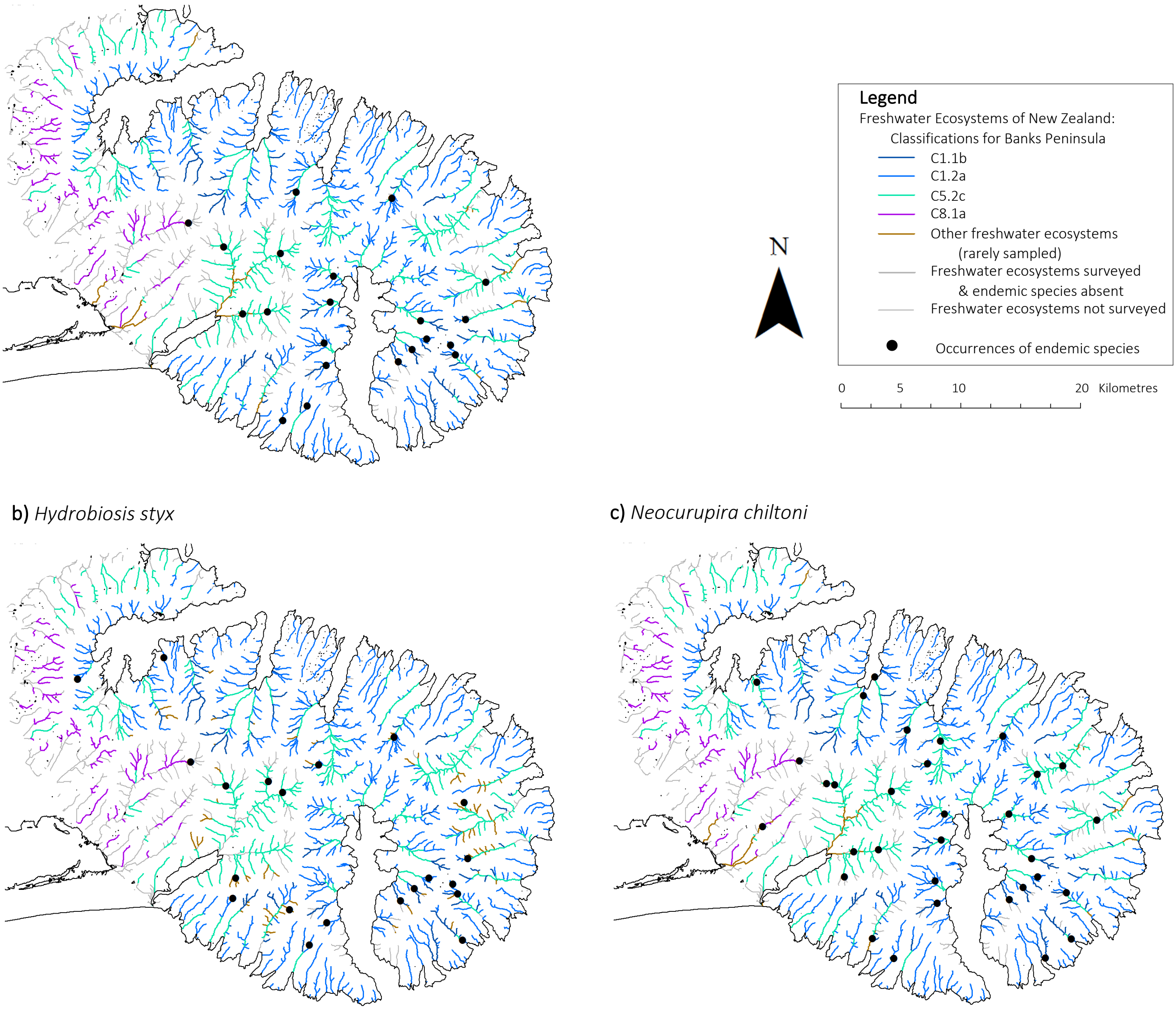
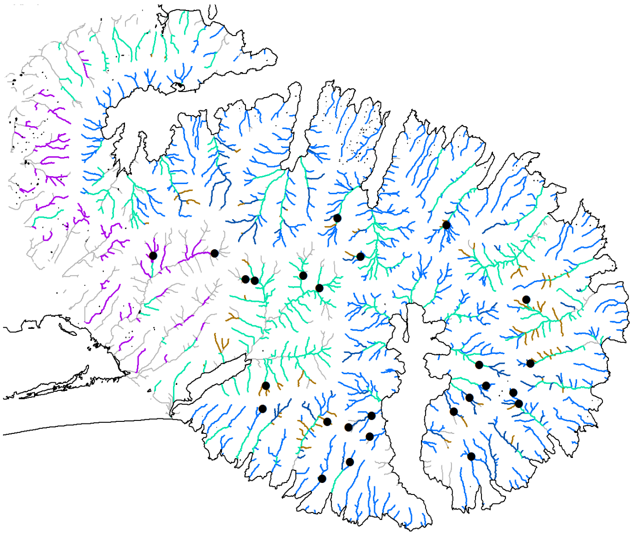
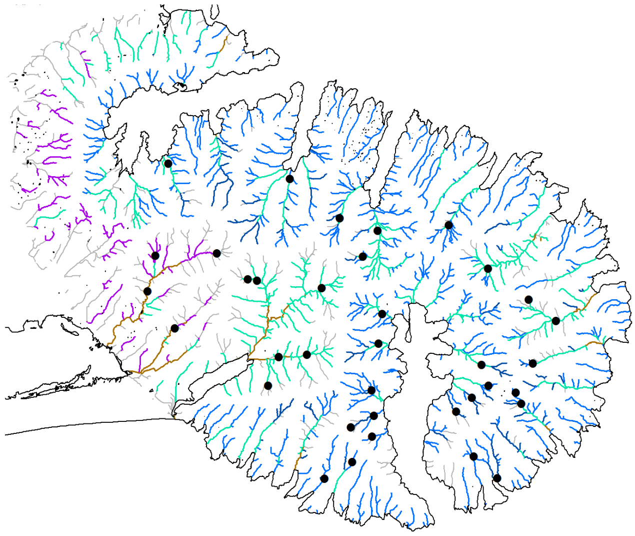


Figure 2.4: The spatial distribution of 300 level Freshwater Ecosystems of New Zealand (FWENZ) of streams on Banks Peninsula where seven regionally endemic stream invertebrates were collected over the 2018/19 summer from a survey of 54 streams. Black data points represent streams where each endemic species was collected. Ecosystems sampled less than three times were grouped for analysis and have been marked as uncommon in the map legend.

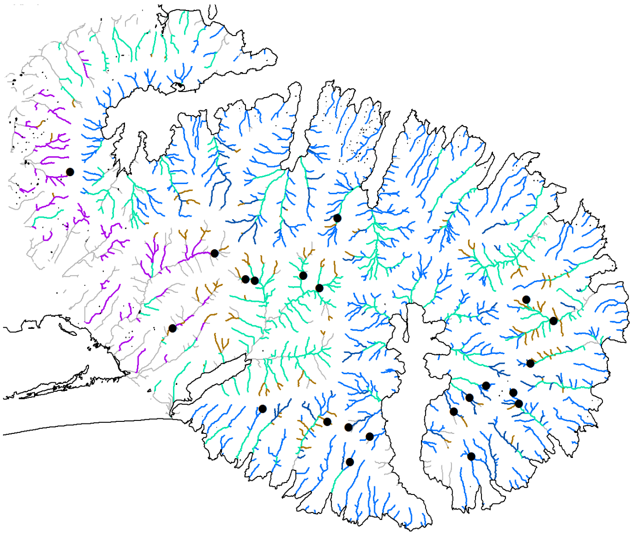
d) *Nesameletus vulcanus*



e) *Orchymontia banksiana*



f) *Zelandobius wardi*



g) *Zelandoperla* sp. 1 (BJF00160; Banks Peninsula)

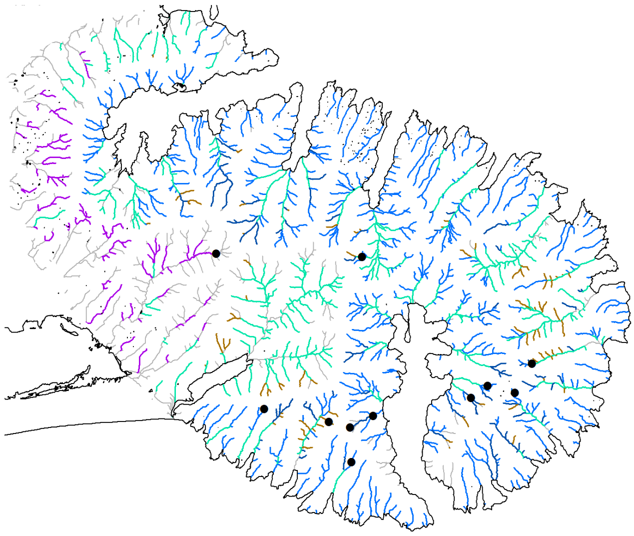


Figure 2.4 continued

2.3.5 Environmental associations

There was a significant ($F_{8,\ 38}$=3.43, p<0.001) relationship between the endemic invertebrate community and the environmental variables (Fig. 2.5). The eight environmental variables used in this model explained 58 % of the variation in the endemic invertebrate community. Altitude was the only environmental variable found to have a significant relationship with the endemic community ($F_{8,38}$=3.93, p<0.01). However, the other environmental variables explain some of the variation in the endemic invertebrate community. Shading, native vegetation, altitude, and stream width drive separation of the community along the horizontal axis CCA1 (Fig 2.5). Channel instability, velocity, depth, and substrate index drive vertical separation along axis CCA2 (Fig 2.5). Although altitude is the only significant variable, it is significantly correlated with both native riparian vegetation cover, and shading (Appendix 3). Therefore, shade cover and native riparian vegetation increase with altitude on the Peninsula. Additionally, as expected substrate size is positively correlated with altitude (Appendix 3). Higher levels of stream shading, native riparian cover, and altitude were associated with the occurrences of *H. styx, N. vulcanus, Z. wardi,* and *Zelandoperla* sp.1 (Fig. 2.5). *Zelandoperla* sp.1 in particular is associated with large boulder and bedrock substrates (Fig. 2.5). *H. styx* is possibly slightly more tolerant of channel instability. Wider, deeper, and faster flowing streams with higher channel stability are associated the occurrences of *C. peninsulae, N. chiltoni,* and *O. banksiana* (Fig. 2.5).

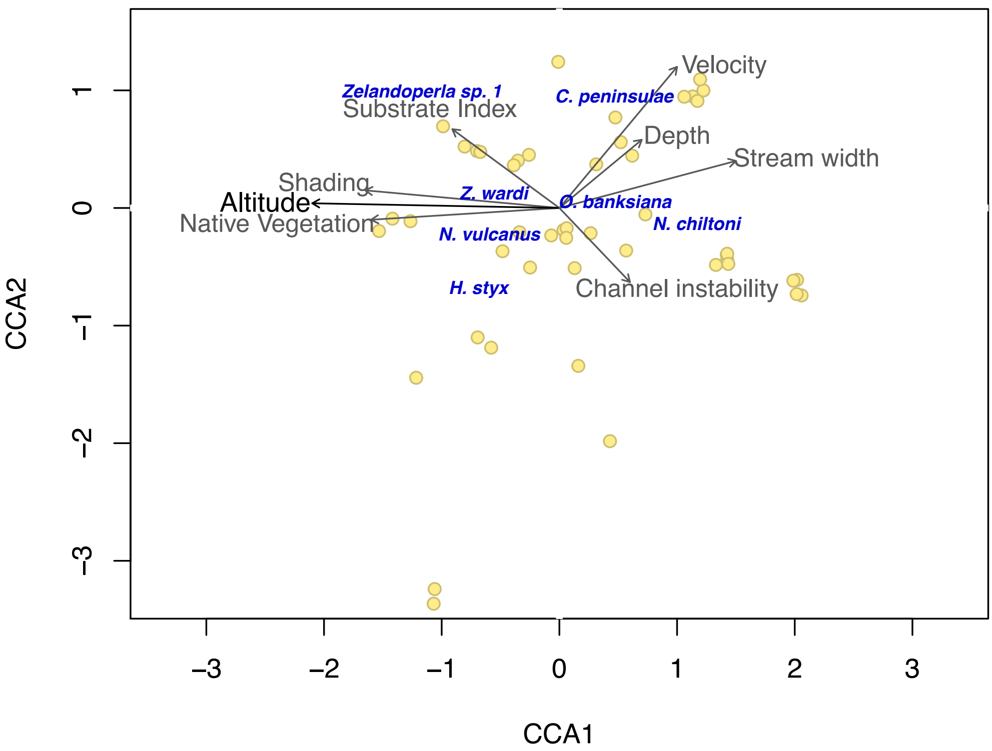


Figure 2.5: Constrained correspondence analysis (CCA) ordination showing the relationship between Banks Peninsula's endemic stream invertebrate community and eight environmental variables. Arrow length represents the influence of each of the eight continuous environmental variables on the invertebrate community. Variables in grey were statistically insignificant and the variable in black (altitude) was found to be statistically significant. Each stream (n=47) where endemic species occurred is represented as a yellow point, while the seven endemic species points are shown in blue.

2.4 DISCUSSION

Of the 10 endemic stream invertebrates found on the Peninsula, seven species were collected frequently in this study; *C. peninsulae, H. styx, N. chiltoni, N. vulcanus, O. banksiana, Z. wardi,* and *Zelandoperla* sp.1. No *Edpercivalia* and only three *Tiphobiosis* individuals were collected. It is possible that the preference of *Edpercivalia* and *Tiphobiosis* to seepage streams adjacent to main river flows may explain why they are missed in standard kick net sampling techniques. Only two species (*N. chiltoni* and *O. banksiana*) were reliably collected on the Peninsula at high abundances. The other species were collected infrequently and occurred at less than half of the streams surveyed. In particular *C. peninsulae* and *Zelandoperla* sp. 1 were rarely collected on the Peninsula.

Overall the occurrence of the endemic species is highest around the central and south eastern areas of the Peninsula. All of the seven endemic species are able to co-occur in the same stream reach. However, in very small high-altitude streams amongst native forest *N. chiltoni* and *C. peninsulae* were not present. The absence of *N. chiltoni* and *C. peninsulae* in small forested streams may be because both of species prefer larger streams (2nd to 3rd order) (Figure 2.5). Furthermore, *N. chiltoni* graze on rock surfaces in fast flowing waters (Craig, 1969), which rarely occur in small forested headwaters. Both stonefly species were commonly found together, however *Zelandoperla* sp. 1 had a more restricted distribution (Fig. 2.2 f and g). The two widely distributed species (*N. chiltoni* and *O. banksiana*) frequently occurred together. However, *O. banksiana* was also found in high elevation forested streams. Although the two free-living caddisfly species can co-occur in the Peninsula's streams, *H. styx* occurred more often in smaller high elevation forested streams than *C. peninsulae.*

2.4.1 Classification performance

2.4.1a Ecological Districts

One aim of this study was to determine if existing classification systems were useful for explaining the distribution of these endemic species. The Ecological Districts showed some correspondence. The Port Hills District is the smallest district, making up only 11 % of the of the Banks Ecoregion (Wilson, 1992). Compared to the other two districts, the Port Hills are largely urbanised, smaller, steeper, drier, and less forested. Other studies investigating the distribution of invertebrates on the Peninsula have also failed to find endemic species in the Port Hills District (e.g. Anderson et al. (2003)), despite the occurrence of regionally endemic plants in the District (Wilson, 1992). The earlier deforestation time of the Port Hills compared to the rest of the Peninsula may have marked the beginning of invertebrate loss in the District. However, climate and topography could have also played a large role in the loss of endemics from the Port Hills. Streams in the northeast of the Port Hills District are mostly small and ephemeral. These streams cannot support the annual life cycles of many of the endemic stream species. This might be particularly important for caddisflies, which require a pupal phase and may struggle to complete their life cycle in the limited wet period (Scarsbrook, 2000). A number of streams in the southwest of the Port Hills flow through regenerating native forest, where two endemic species were collected (Fig. 2.2 b and f). Despite the presence of these forested streams other endemics may remain restricted to the Akaroa and Herbert Districts. This is possibly because the Port Hills District lacks higher elevation streams, reliable precipitation, and larger permanent stream networks. Isolation is another factor that may be influencing endemic occurrence in the Port Hills District. The Port Hills and Herbert Districts have always been separated by the Lyttelton Harbour, but now the land at the head of the Harbour is in pasture. This pastural area is likely to be inhabitable for many of the endemic species as it is sparsely forested and consists of ephemeral streams. Although flighted endemics (e.g. *N. chiltoni*) may be able to disperse across this area of unsuitable habitat, it is unlikely *Zelandoperla* sp. 1 will ever be able to disperse to the Port Hills District as it is flightless. Because there is no historic record of the other endemic stream invertebrates occurring in the Port Hills District, it is also possible they never occupied this part of the Peninsula.

C. peninsula, N. chiltoni, N. vulcanus, and *O. banksiana* occurred at significantly different proportions across the three Ecological Districts, because they frequently occurred in the Herbert and Akaroa Districts but were absent from the Port Hills District. Higher levels of native riparian vegetation, stream shading, and higher altitudes were associated with the occurrences of *N. vulcanus,* while larger streams were associated with *C. peninsulae, N. chiltoni,* and *O. banksiana* (Fig 2.5). The Akaroa and Herbert Districts supported more of these habitats than the Port Hills District. These two districts are larger, have higher elevations, more native forest, and a larger network of permanent waterways, therefore might support higher diversity.

Zelandoperla sp. 1 was rarely collected. The stonefly prefers small streams with large substrates (e.g. bedrock) at higher elevations (Fig 2.5). Although the stonefly was not collected from the Port Hills District, it was only collected twice in the Herbert district (Fig 2.5). It is likely that the stonefly's restricted range and low collection rate (20 %) was too small to detect statistical differences between the Ecological Districts.

The Ecological District concept is a terrestrial based classification defined by local topography, geology, soils, vegetation, and human development (Nicholls, 1979). Although the Ecological Districts can explain the distribution of some endemic species, they are large areas that include a wide range of stream systems. Often the Ecological District boundaries did not match the distribution of the endemics (e.g. *N. vulcanus* (Fig. 2.2d)). Ecological District analysis shows there is poor endemic representation in the Port Hills District and roughly similar representation across both the Akaroa and Herbert Districts. These Ecological Districts seem to be too broad to specify certain stream environments and habitats where the endemic stream invertebrates occur and therefore cannot guide specific conservation management of these taxa.

2.4.1b River Environment Classification

The REC showed that the number of endemic species and the occurrences of four endemic species differed significantly across the nine different environments recognised on the Peninsula (Fig. 2.3). All six categorical variables that define the River Environment Classification were used in this study because of the small scale the study is set at. However, some of the six variables showed little variation over the Peninsula. Both geology and land cover were very homogenous, as most of the Peninsula was classified with volcanic basic geology and pastural land cover. Because the Peninsula is a relict volcano highly homogenous geology was expected. However, land cover was not expected to be so uniform across the Peninsula. REC land cover is classified using the 1997 version of the Land Cover Database (LCDB) (Snelder et al., 2010). The resolution of the LCDB is limited and cannot differentiate between levels of agricultural intensity (Snelder et al., 2010). Much of the Peninsula's agriculture is low intensity and a number of areas have been retired, protected, and have begun to regenerate native vegetation since 1997. Several survey locations classified as "pastural" had very little pastural land in the catchment above the stream reach surveyed. Instead these catchments were covered by scrub or forest (e.g. stream 27-A). The lack of land cover definition recognised by the REC may be an issue for *H. styx, N. vulcanus, Z. wardi,* and *Zelandoperla* sp. 1, which were associated with higher stream shading and native riparian vegetation (Fig. 2.5). If the REC land cover data was updated, stronger associations are expected to be seen between the endemic species and the REC at the land cover level.

The occurrences of *N. chiltoni, N. vulcanus, Z. wardi* and *Zelandoperla* sp. 1 differed significantly across the REC defined environments, suggests these taxa are spatially restricted and show preference to certain stream environments. *N. chiltoni* was associated with medium order streams in cold dry climates and in cold wet climates low order and low source of flow streams (Fig. 2.3 c). The blephariceriid was never collected from small lowland streams in cold dry climates. *N. vulcanus* and *Z. wardi* were strongly associated with hill sourced streams, with steep gradients in cold wet climates (Fig. 2.3 d and f). *N. vulcanus* and *Z. wardi* can occur in both medium order and low order streams, but rarely occurred in cold dry climate streams (3rd and 4th order) with a low source of flow. Both *N. vulcanus* and *Z. wardi* never occurred in cold wet or cold dry climate streams with a low source and pastural land cover. *Zelandoperla* sp. 1 was strongly associated with streams classed as hill sourced, low order, and with high gradient valley landforms (Fig. 2.3g). The *C. peninsulae, H. styx,* and *O. banksiana* showed little environmental preference, suggesting they are more generalist taxa (Fig. 2.3).

The REC is able to differentiate stream size through the network position (stream order) class. This is important because stream width is associated with endemic species occurrence (Fig. 2.5). Different endemic species tend to favour either small streams (e.g. *Zelandoperla* sp.1) or larger order streams (e.g. *N. chiltoni*). The REC climate and network position levels are also able to differentiate between low order streams that are permanent and streams that warm or dry in summer on the Peninsula. This is a major advantage of the REC as many of small order streams near the coast on the Peninsula cannot support certain stream invertebrates (e.g. the environment CD/L/VB/P/LO/HG). For example, stoneflies need to grow and moult several times before finally emerging as soft-bodied adults, this process can take several months or even years and therefore requires constant water (McLellan, 1999, Winertbourn, 2010).

There have been very few studies using all six variables of the REC to explain the distribution of particular stream invertebrates in New Zealand, especially regionally endemic species. This study shows an ecological difference in some of endemic species across the Peninsula's REC defined environments. However, a study by Inglis et al. (2008) in the Auckland Region did not find any meaningful ecologically differentiation in stream invertebrates across river environments defined by the first four categories of the REC. Inglis et al. (2008) suggested that a large limitation of the REC in their study was the resolution of the data used to classify the streams. In my study I also found the resolution of certain categories in the REC to be limiting, especially land cover. Additionally, another study by Chakraborty (2008), suggests the REC is optimised at the geology or third level of the classification. Chakraborty (2008) found that when land cover was included in analysis it did not add any additional explanation of the stream invertebrate communities. However, this is probably because most of the study streams used by Chakraborty (2008) were in forested streams. Although both Inglis et al. (2008) and Chakraborty (2008) only used the first few categories of the REC classification (watershed climate, topography, geology, and land cover), using all six categories of the classification was fundamental in explaining the distribution of Banks Peninsula's endemic species. Network position was particularly important for explaining the occurrence of species such as *C. peninsula* and *N. chiltoni,* because these species favour larger 3rd and 4th order streams. While, valley gradient and climate were important for species such as *Zelandoperla* sp. 1, which prefer steep streams with large substrates in cold wet climates.

The REC environments are naturally unevenly represented across the Peninsula. Some environments are rare, and others are common. There are two main environments that dominate the Peninsula and therefore were sampled more frequently. These two dominant stream environments are both steep and consist of small order streams. However, the common environment sourced from hills in cold wet climates frequently supports endemic species, while in the other cold dry lowland environment rarely supported endemics. Based on the REC, I suggest the conservation of these endemic species should focus around the cool wet climate, high and moderate gradient environments on the Peninsula. All seven of the endemic species occurred in these environments, which cover much of the central Peninsula. However, environmental heterogeneity can help promote species diversity and genetic diversity. Species diversity is important for ecosystem functionality and within species diversity is important for species resilience. Therefore, rare environments that support unique communities and diversity should also be considered when accessing stream invertebrate conservation using the REC.

2.4.1c Freshwater Ecosystems of New Zealand

National-scale environmental and conservation management assessment of macroinvertebrates are recommended to use the 100 level FWENZ classification, while the higher resolution 200 and 300 levels are recommended for smaller regional and local analysis (Chakraborty, 2008, Leathwick et al., 2010). However, the 100, 200, and 300 levels of FWENZ were unable to explain the variation in the number of endemics across the Peninsula. The 100-level classification was not expected to explain the variation in the endemic species richness across the Peninsula, because this study is focused at small regional scale. My findings are consistent with Chakraborty (2008) who showed that within ecoregions community composition cannot be differentiated by the 100 level ecosystems recognised by FWENZ. The higher classifications (200 and 300) of FWENZ were expected to explain the distribution of the endemic species over the region based on the outcomes of other studies (e.g. Chakraborty (2008)).

The number of different ecosystems recognised by FWENZ on the Peninsula was limited in comparison to environments recognised by the REC. Only nine ecosystems were surveyed at the largest (300) FWENZ level, comparted with the 17 environments recognised by the highest classification of the REC. Additionally, like the REC, FWENZ ecosystems are not represented equally on the Peninsula. The maritime ecosystems C5.2c (highly shaded, moderate gradient small streams) and C1.2a (highly shaded, steep gradient small streams) dominate. FWENZ has been developed from environmental variables that are predictors of biological patterns in river ecosystems, such as mean annual flow and air temperature (Leathwick et al., 2010). These types of environmental variables have proximal influences on biological processes, opposed to the indirect gradients of environmental variables (e.g. geology and valley gradient) used to define the REC and Ecological Districts (Chakraborty, 2008, Leathwick et al., 2010, Snelder et al., 2010). It is likely that the environmental variables that define FWENZ are either similar across the Peninsula or cannot be differentiated at a fine enough resolution to decipher the Peninsula's different river ecosystems. For example, many of the 1st order ephemeral streams that run directly into the ocean had few or now endemics. However, these coastal streams share the same 300 level FWENZ classification as 1st and 2nd order high altitude streams in the central area of the Peninsula, where all seven endemics occur (e.g. the ecosystem C1.2a (Fig. 2.4)). These two types of streams are quite different. Small streams near the sea often have small catchments, are dry in summer, and have less forest cover compared with small high-altitude streams on the Peninsula.

N. chiltoni was the only endemic species whose occurrence was explained by the 300 level FWENZ classification (Table 2.4 and Fig. 2.4c). This is because the blephariceridl was found to occur rarely in C1.2a, a small steep highly shaded stream ecosystem (Fig. 2.4c). This ecosystem (C1.2a) occurs widely across the Peninsula and includes 1st to 3rd order streams. *N. chiltoni* prefer faster flowing waters (Craig, 1969) and large order streams presumably so they can feed off algae on rock surfaces. The streams in the C1.2a ecosystem may be too small, shaded, slow, or too high in organic content for the blephariceridl. However, my analysis of FWENZ suggests that the six other endemic species occur in a broad range of ecosystems, despite some taxa having highly restricted distributions and showing associations with variables such as altitude.

To my knowledge there have been no other studies using FWENZ (or the REC) that look specifically at the distribution of regionally endemic streams invertebrates. However, FWENZ has been used to model the distribution of some freshwater invertebrate families and genera at a national scale in New Zealand by Leathwick et al. (2009). These spatial estimates of invertebrate distribution were formed by combining field data and environmental predictors of FWENZ, which were then applied to separate statistical models for each taxon to determine the relationship between occurrence and the FWENZ environmental predictors (Leathwick et al., 2009). The modelled distributions of the genera and families of the seven endemic species produced by Leathwick et al. (2009) do not match the distributions determined in this study. These modelled distributions tend to over or underestimate the distribution of the regionally endemic species' genera or families on the Peninsula (Appendix 5). Some of the endemic species have multiple representatives of their family or genera on the Peninsula (e.g. *Hydrobiosis*). Therefore, the *Hydrobiosis* genera was predicted to occur commonly and widely across the Peninsula. However, other endemics species are the sole representative of certain families and genera on the Peninsula (e.g. *C. peninsulae, N. chiltoni,* and *O. banksiana*) meaning their predicted distributions should be similar to my findings. But the predicted models of Leathwick et al. (2009) failed to pick up the wide and abundant distributions of *N. chiltoni* and *O. banksiana,* suggesting they had a low probability of occurring across much of the Peninsula (Appendix 5). These large-scale modelled distributions of Leathwick et al. (2009) also suggest that it is incredibly difficult to use FWENZ to explain or predict the distribution of regionally endemic species on the Peninsula.

2.4.2 Comparisons to previous studies

Despite the Peninsula once being completely forested, several of the endemic species seemed to be decoupled from shaded and forested streams (Fig. 2.5). Although *N. chiltoni* and *O. banksiana* were collected from forested and well shaded streams, they were found at streams with no native riparian vegetation and where shading was low (≤ 15 %). Because stream systems are ruled by their surrounding valley environments (Hynes, 1975) it is possible that the occurrences of endemic species in poorly shaded and forested areas could be facilitated by forested headwaters upstream. Forested headwaters could be facilitating cooler temperatures in some lowland streams and increasing the dissolved oxygen levels. For example, the lowland stream at the base of the Peraki Creek (19-SB) had little shading and native vegetation cover, but the stream temperature was still cool (13°C) and the dissolved oxygen was high (10.7 ppm). However, in several areas *N. chiltoni* and *O. banksiana* were collected in catchments with poorly forested headwaters (Fig. 2.2 c and e). The high channel instability tolerances (Fig. 2.5) of these two species is perhaps why they can survive in these poorly shaded and unforested streams. *N. chiltoni* and *O. banksiana* were the two most abundant and commonly occurring endemic species collected from the Peninsula. Although the abundances of these two species is likely to be partly related to the time of year they were collected, species with larger populations are known to be less sensitive to habitat fragmentation (Henle et al., 2004). The success of these two invertebrates on the Peninsula is due to a combination of factors. Their ability to thrive in less stable streams with little shading and potentially no native vegetation, combined with their high abundances and wide distributions has allowed them to thrive after major deforestation and habitation fragmentation on the Peninsula. The extensive distribution of *N. chiltoni* in a range of forested and unforested environments from near sea level to about 300 m a.s.l. is consistent with the findings of both Craig (1969) and Harding (2003). It appears that the distribution of *N. chiltoni* has remained relatively unchanged across Banks Peninsula over the last 50 years since the study of Craig (1969).

Prior to this study *C. peninsulae* was thought to be restricted to medium and small streams in forest fragments from sea level to 475 m a.s.l. (Ward, 1995, Smith, 2002, Harding, 2003). In this study *C. peninsulae* were collected from a similar altitude range to previous studies. However, the caddisfly was not collected from any streams that flow into the Lyttelton Harbour or streams in the most eastern part of the Peninsula (e.g. Flea Bay and Stoney Bay) where they have previously been recorded by Ward (1995). *C. peninsulae* occurred in shaded and poorly shaded streams, and forested and unforested streams, but generally favoured wider 3rd order streams (Fig. 2.2a). In some cases, pristine headwater streams may be facilitating the persistence of the species in larger streams (e.g. Okuti River). However, *C. peninsulae* is a low abundance species (Fig. 2.2a), making it more vulnerable to future habitat change compared to most of the other regionally endemic species collected in my study.

The restriction of stream invertebrates to forest streams is not uncommon in New Zealand. For example, the cased caddisfly *Zelandopsyche ingens* only occur in beech forest streams, the chironomid *Harrisius pallidus* are found only on decomposing wood in forested mountain streams, and the cased caddisfly *Olinga jeanae* only resides in forest streams (Winterbourn et al., 2006). Four of the endemic species (*H. styx, N. vulcanus, Z. wardi,* and *Zelandoperla* sp. 1) were only collected from streams with high shading and native riparian vegetation or immediately downstream of forest patches. All four species generally occurred infrequently and at low abundances, this combined with their restriction to forested headwater streams makes them particularly susceptible to habitat fragmentation. Altitude was the only environmental variable to have a statically significant relationship with the community composition of endemic species. The significance of altitude is probably driven by *H. styx, N. vulcanus, Z. wardi,* and *Zelandoperla* sp. 1, which occurred more frequently at altitudes above 80 m a.s.l.. Because substrate size generally increases with altitude (Harding et al., 2009), these endemic species were often collected from small headwaters (1st and 2nd order streams) with large substrate sizes. On the Peninsula altitude is also underpinned by the presence of remnant and regenerating native vegetation, especially over 80 m a.s.l.. More native vegetation at higher altitudes on the Peninsula may be a relic of inaccessibility for scrub and forest clearing, the result of uneconomical farmland retirement, or more favourable conditions for forest regeneration. However, because there is no information on the endemic species from prior to the Peninsula's deforested, I cannot determine whether *H. styx, N. vulcanus, Z. wardi,* and *Zelandoperla* sp. 1 have always preferred forested headwaters or have taken refuge in these higher environments since the deforestation of the Peninsula.

The distribution of *N. vulcanus* appears to have shrunken towards the central and eastern areas of the Peninsula since the 90's, when specimens were collected for their formal description (Hitchings and Staniczek, 2003). In this study the mayfly was not collected from the streams surrounding the Lyttelton Harbour and in the Okuti River where they have previously been collected (Hitchings and Staniczek, 2003). *N. vulcanus* no longer seem to be found down to sea level on the Peninsula, as suggested by Hitchings and Staniczek (2003). It is now possible *N. vulcanus* may be restricted elevations > 80 m above sea level. The abundances of *N. vulcanus* were generally low (< 10) except for several streams in the Akaroa District, where > 20 *N. vulcanus* individuals were collected (Fig. 2.2d). The high abundance of *N. vulcanus* at certain stream reaches may be attributed to the absence of fish. Introduced sportfish species are known to have strong predatory effects on *Nesameletus* spp. populations in New Zealand (McIntosh, 2002). Although introduced sportfish are not common on the Peninsula, it is likely may indigenous fish species also consume *Nesameletus*. Given the steep gradient and alternating riffle pool structure of the Peninsula's waterways a number of the streams where I collected invertebrates are above natural fish barriers, such as waterfalls.

H. styx and *Z. wardi* occurred at low abundances in forested streams across the Peninsula. This is consistent with the findings of Harding (2003), where these species were found at low abundances in forested headwaters. The results from this study also suggest that *H. styx* and *Z. wardi* are also able to persist in larger forested 3rd order streams (Fig. 2.2 b and f). Lastly, *Zelandoperla* sp. 1 was only collected from a handful of headwater streams in low abundances. The limited spatial distribution and low collection abundances of the stonefly make it extremely vulnerable to habitat change (Fig. 2.2g). Wing reduction is a common trait in stoneflies, which develops frequently in alpine areas or isolated habitats in response to flighted emigrating individuals being unable to establish in surrounding viable environments (Veale et al., 2018). *Zelandoperla* sp. 1 diverged from sister taxa < 10 Ma, around the same time as *Z. wardi* when Banks Peninsula was an island (McCulloch et al., 2016). Therefore, the wing reduction of *Zelandoperla* sp. 1 is not unexpected given the historic geographic isolation of Banks Peninsula. However, the stonefly's highly reduced wing pads (Veale et al., 2018), mean the flightless species has very limited dispersal potential and will likely struggle to recolonize as forested habitats improve. As native vegetation on the Peninsula continues to regenerate and more streams may become suitable for these endemics. Therefore *Zelandoperla* sp. 1 and the other endemic species distributions are expected to expand downstream from the forested headwaters that have provided refuge.

2.4.3 Conclusions

Invertebrates that are poor dispersers and show high levels of endemism, such as Banks Peninsula's regionally endemic stream invertebrates, are amongst some of the most 'threatened' freshwater invertebrate species (Collier et al., 2016). Despite the high number of 'threatened' freshwater invertebrates in New Zealand and the nation's declining water quality there is still little research into, and conservation of freshwater invertebrates. Banks Peninsula's regionally endemic species were particularly hard to classify using multivariate river classification systems as most of the habitat heterogeneity relevant to these species is lost at the small spatial scale of the Peninsula. Additionally, aspects of these classifications do not reflect the current conditions of Banks Peninsula and are lagging behind the rapid growth of regenerating forest in the area. The Ecological Districts and 300 level FWENZ classification are too broad to explain the distribution of the endemic stream invertebrates and guide their conservation. The REC was the most useful of the three classifications tested, suggesting that Banks Peninsula's regionally endemic stream invertebrates are most common in cold wet climates in small steep streams with hill sources. Although Banks Peninsula has undergone significant historic deforestation, at least seven of the Peninsula's regionally endemic stream invertebrates are still persisting. The protection of forested headwater streams in the central area of the Peninsula is critical for the survival of these unique stream invertebrates.

Chapter three:

Banks Peninsula's stream invertebrates: diversity, community structure, and environmental preference

3.1 INTRODUCTION

3.1.1 Characteristics of New Zealand stream invertebrates

New Zealand has approximately 660 described species of freshwater invertebrates that belong to a unique assemblage (Collier, 1993, Grainger et al., 2018). Most of New Zealand's freshwater invertebrate families are limited to New Zealand or the Southern Hemisphere (Collier, 1993). An estimated 90% of New Zealand's freshwater invertebrates are endemic (Boothroyd, 2000, Harding, 2005). Many freshwater invertebrate groups that are common overseas are rare or not represented in the New Zealand fauna. For example, New Zealand has no stoneflies from the families Perlidae, Perlodidae, and Pteronarcidae, which are common in Northern Hemisphere (Collier, 1993). Additionally, in New Zealand there is also a large number of wingless stoneflies (Veale et al., 2018), which is an uncommon stonefly trait. Other freshwater invertebrate orders in New Zealand show low levels of speciation compared to the Northern Hemisphere. For example, mayfly diversity in New Zealand is restricted to 59 recognised species (Grainger et al., 2018) and is dominated by the family Leptophlebiidae (Collier, 1993). While, in North America mayfly diversity is high and is dominated by the family Baetidae (Collier, 1993). New Zealand also has a number of primitive freshwater insect groups still present amongst its assemblage, such as the beetle family Hydraenidae (Collier, 1993). New Zealand's freshwater invertebrates follow a pattern of high endemism that is similar to the rest of the country's biota. New Zealand's unique stream invertebrate assemblage is likely to be a response to the country's early separation from Gondwana and more recent volcanic, seismic, and glacial activity (Boothroyd, 2000, Harding, 2005).

Insects, such as mayflies, stoneflies, and caddisflies account for about 80 % of our freshwater invertebrate diversity (Boothroyd, 2000). However, invertebrate communities in stony New Zealand streams are frequently characterised by a set of common taxa. These taxa include the mayflies *Deleatidium* and *Coloburiscus,* the stoneflies *Stenoperla, Zelandobius,* and *Zelandoperla,* the free-living caddisflies *Aoteapsyche, Hydrobiosis,* and *Psilochorema,* the cased caddisflies *Olinga* and *Pycnocentria,* the dobsonfly *Archichauliodes,* Elmidae beetles, the snail *Potamopyrgus* and chirnomids (Boothroyd, 2000).

3.1.2 Stream invertebrate diversity

Invertebrate communities reflect their surrounding catchment characteristics and larger scale landscape processes (e.g. climate and geology) (Hynes, 1975, Allan et al., 1997, Harding and Winterbourn, 1997, Death and Collier, 2010). Therefore, the diversity and structure of stream invertebrate communities is affected by both local and regional environmental factors (Harding et al., 1998, Death and Joy, 2004, Harding, 2005, Barquín and Death, 2006, Death and Collier, 2010). In New Zealand, stream invertebrate communities differ spatially between ecoregions (Harding and Winterbourn, 1997) and between stream reaches across physical gradients, such as physical disturbance (Barquín and Death, 2006) and shading (Death and Collier, 2010). Stream invertebrate diversity is determined by both catchment and reach factors (Boothroyd, 2000). The strength of factors that influence diversity depend on the scale they are observed (Boothroyd, 2000). For example, the geology and biogeography of a region (e.g. volcanism and isolation) may restrict the diversity of a region, such as Banks Peninsula. However, geology may have very little impact on stream invertebrate diversity at a local scale on Banks Peninsula because it is largely homogenous across the Banks Ecoregion. Instead local scale diversity may be more strongly influenced by heterogeneity (e.g. variable riparian vegetation or substrates).

Regional or gamma (γ) diversity is influenced primarily by factors such as latitude or the terrestrial biome, while local or alpha (α) diversity is influenced by an array of factors such as surface complexity, habitat type, and shading (Boothroyd, 2000). It is often hard to link local diversity to regional diversity because there are many drivers of community composition and diversity at a reach scale in streams. Beta (β) or watershed/catchment diversity provides a link between local diversity and regional diversity. Based on the species energy hypothesis proposed by Currie (1991) there are three main drivers of beta diversity; dispersal limitation, environmental heterogeneity, and productivity. Dispersal limitation is affected by invertebrate traits, the spatial arrangement of communities, and the legacy of historical events (e.g. volcanism or deforestation) (Astorga et al., 2014). Given the extensive historic deforestation of Banks Peninsula, it is likely many stream invertebrates in the region are dispersal limited and are restricted to isolated populations.

Diversity is expected to be higher with increasing levels of environmental heterogeneity and productivity (Currie, 1991). Beta diversity is commonly associated with longitude, as diversity tends to increase towards the equator (Currie, 1991). This pattern is seen because longitude is associated with a suite of environmental variables that regulate biology and productivity, such as temperature, daylight hours, and precipitation, which all increase towards the equator allowing diversity to increase (Astorga et al., 2014). In New Zealand, the diversity of mayflies follows this global trend. Pohe (2019) found that mayfly diversity increases towards the north and decreases with increasing altitude. However, Astorga et al. (2014) found that the diversity of stream invertebrates in New Zealand generally increased towards the south, based on a study of eight regions across the country. They suggested that this southward diversity increase was driven by habitat heterogeneity (Astorga et al., 2014).

The spatial patterns of New Zealand's stream invertebrate diversity seem to be complex. Our country has been affected by a range of geological and climatic events that have influenced diversity (Boothroyd, 2000). In certain areas strong regional endemism has developed (e.g. Nelson, Fiordland, and Banks Peninsula) (McLellan, 1990) and the genetic diversity of some stream invertebrates appears to have been restricted by glaciation (e.g. the mayflies *Siphlaenigma janae* and *Isothraulus abditus* (Pohe, 2019)). Regardless of the lack of consistency shown in diversity patterns a national scale, local stream invertebrate diversity is driven by numerous variables that tend to show consistent patterns across New Zealand (e.g. diversity increases with stream shading (Death and Collier, 2010)).

3.1.3 Impact of deforestation and pastural development on stream invertebrates

Much of New Zealand has been deforested since human arrival, in particular the east coast of the South Island (Ewers et al., 2006). In New Zealand the clearance of native forest for pastural development may not always result in significant declines in local stream invertebrate diversity (Townsend and Arbuckle et al., 1997). However, the community structure of impacted streams is expected to shift over time, with sensitive taxa such as stoneflies being lost and replaced by tolerant taxa such as *Potamopyrgus antipodarum* (Boothroyd, 2000). The conversion of forested headwaters to pasture is a particular issue, as forested headwaters frequently have high local diversity (Death and Collier, 2010), which contributes considerably to regional diversity (Boothroyd, 2000). Deforestation and pastural land development reduce the heterogeneity of catchments and regions, thus reducing both gamma and beta diversity (Boothroyd, 2000). Research carried out by Stone and Wallace (1998) suggests that invertebrate communities take in excess of 16 years to recover from deforestation to pre-logging levels, even when forests are replanted. Furthermore, work by Harding et al. (1998) indicates historic agricultural land use can limit present day stream invertebrate communities and reduce the capacity for stream recovery. In other words, invertebrate communities in regenerating forested streams may still reflect agricultural or unforested conditions decades after adjacent land use has improved (e.g. reforested) (Harding et al., 1998).

On Banks Peninsula over 99 % of the pre-human indigenous forest has been removed through historic land clearance and logging (Burrows, 1998, Harding, 2003, Ewers et al., 2006, Wilson, 2013b). However, native forest and shrublands predominately of kānuka have begun to regenerate on the Peninsula and by 2013 around 15 % of the region was estimated to be covered by native forest or shrubland (Wilson, 2013b). Nevertheless, much of the land above 300 m is still dominated by tussock, while most valley floors are used for agriculture. As a result of land use change, Banks Peninsula's streams have probably experienced shifts in community composition. The community composition of stream invertebrates differs across forested, pastural, and mixed (forested and pastural) streams on the Peninsula (Harding, 2003). Forested streams are dominated by mayflies, caddisflies, and two-winged flies, while mixed and pastural streams are dominated by two-winged flies, snails, and caddisflies (Harding, 2003).

Banks Peninsula has 10 regionally endemic stream invertebrates. These endemic stream invertebrates frequently occur in forested headwaters and within forest fragments (Harding, 2003), thus only contribute to the diversity of selected stream reaches or particular catchments. In New Zealand forested headwaters are known to contribute markedly to diversity (Death and Collier, 2010). Therefore, the conservation and restoration of forested headwaters is important for stream invertebrates (Death and Collier, 2010). Given the preferences of Banks Peninsula's endemic species to forested streams and the widespread historic deforestation of the Peninsula (Harding, 2003), streams in isolated forest patches are likely to be hot spots of diversity on the Peninsula.

3.1.4 Macrohabitat preference of stream invertebrates

Many stream invertebrates display microhabitat preferences (Jowett et al., 1991, Death and Collier, 2010). Within a stream reach there will often be a range of small microhabitats due to variations in water velocity, depth, differences in substrate size and compactness, in-stream vegetation, and a range of organic matter types (Death, 2000). For example, water velocity can vary from fast flowing cascades and riffles of white water, to slow moving backwaters, eddies, and pools over a short distance. Several studies have reported that stream invertebrate taxa differentiate between substrate types (e.g. coarse substrates, soft substrates, and organic substrates) (Jowett et al., 1991, Death, 2000). Some taxa are extremely sensitive to fine sedimentation, especially Ephemeroptera, Plecoptera, and Trichoptera. These sensitive taxa are often lost from streams where cobbly substrates are covered by sediment and replaced by non-insect invertebrates such as worms and snails (Burdon et al., 2013). Moss substrates are known to be diverse habitats in New Zealand streams, and frequently are recorded showing high levels of invertebrate diversity (e.g. Cowie and Winertbourn (1979)). Suren (1991) reported stream invertebrate abundances to be up to 10-fold higher in mosses compared to stony substrates. In New Zealand mossy substrates support a range of invertebrates from Nematoada and Chironomidae to Tricoptera and Ephemeroptera (Death, 2000). Leaf litter in New Zealand streams is also a vital resource for some taxa, such as the stoneflies *Austroperla cyrene* and *Zelandobius* (Death, 2000). Furthermore, some taxa such as *Zelandopsyche ingens* use beech tree leaves to construct their cases and therefore are only ever found in beech forests (McIntosh et al., 2005). Other stream invertebrates such as *Coloburiscus humeralis, Zelandoperla,* and *Aoteapsyche* show strong preferences to fast flowing coarse substrate riffle type habitats

(Jowett et al., 1991). Determining the microhabitat preferences of stream invertebrates is often complicated. Some taxa show little preference and others do not show preferences consistently (Minshall, 1984). For example, some of the most common and abundant stream invertebrates in New Zealand, such as *P. antipodarum* and *Deleatidium* spp. show little microhabitat preference (Jowett and Richardson, 1990, Jowett et al., 1991).

Most of the streams on Banks Peninsula are relatively short (generally < 10 km long) and steep. Based off the River Environment Classification the majority of streams on the Peninsula have gradients > 4 %. Therefore, many 1st and 2nd order tributary streams are dominated by riffle and pool sequences. Because steep streams dominant the Peninsula it is possible that the microhabitat preference of stream invertebrates may show weaker preference patters or clear portioning between microhabitats on the Peninsula. Given the high level of regional endemism among Banks Peninsula's stream invertebrates it is possible that some of these endemic species have developed microhabitat preferences and full highly specialist niches. For example, the blephariceridae *Neocurupira chiltoni* has shown in previous studies some preference towards faster flowing waters (Craig, 1969).

3.1.5 Study objectives and aims

Banks Peninsula has been isolated for the majority of the last 20 Ma (Soons et al., 2001, Timm et al., 2009). Therefore, some of New Zealand's stream invertebrate orders, genera, or species commonly found around the rest of the South Island may be completely absent from the Peninsula or occur rarely, while other less common taxa could be abundant.

In this chapter I use the survey data from chapter two to investigate the following questions:

1. *Does stream invertebrate diversity differ spatially across the Peninsula and is there a consistent diversity pattern at differing spatial scales?*
2. *Are some stream invertebrate taxa absent, under-represented, or over-represented on Banks Peninsula compared to other New Zealand streams?*
3. *What is the structure of stream invertebrate communities on Banks Peninsula?*
4. *Lastly, do certain key taxa show microhabitat preferences? Are microhabitat preferences strong amongst the regionally endemic species and have some species developed specialist niches?*

I hypothesised that diversity would be highest in the east and south of the Peninsula where there is more forest and higher densities of permanent streams. I predicted taxonomic richness and community composition to be associated with abundant stream shading and/or native riparian vegetation. However, differences in water chemistry were not expected to explain any community composition variation. Certain taxa were expected to favour specific microhabitats, particularly riffles and organic matter. For example, *N. chiltoni* were expected to be collected more often in fast flowing habitats, such as riffles and runs.

3.2 METHODS

3.2.1 Field survey

3.2.1a Invertebrate collection

I conducted a field survey of 54 Banks Peninsula streams, as outlined in the methods of chapter two. Benthic invertebrate samples were collected between December 2018 and February 2019. Survey streams were chosen to provide spatial coverage across the whole Peninsula in a range of habitats, from old growth podocarp forest and regenerating native scrub to pastural land. Individual kick net samples (250 µm mesh) were collected. When present, kick net samples were collected from four instream microhabitats: riffles, runs, pools, and organic matter (i.e., leaves, twigs and woody debris). Samples from each microhabitat were kept separate. In this study riffles were defined as fast flowing or cascading areas with broken surface water. Runs were classified as areas of fast flowing water with a smooth surface. Pools were defined as slow flowing back eddies or deep slow flowing sections with smooth surfaces. Organic matter samples were collected amongst submerged leaf litter, wood, moss, macrophytes, and tree roots. Further detail on stream selection and invertebrate collection can be found in the methods section of chapter two (p. 23).

3.2.1b Water chemistry and habitat sampling

At each of the streams surveyed spot water chemistry measurements were taken using handheld meters. Dissolved oxygen (mg/l) and temperature (°C) were measured using an EcoSense ODO200 probe, while pH and conductivity (μS_{25} cm^{-1} at 25°C) was measured using a YSI Pro 1030 meter. Turbidity was measured using a HACH 2100P portable turbidimeter.

Habitat measurements of riparian vegetation, stream shading, stream stability, locality (altitude and GPS position), stream width, stream depth, and water velocity were collected at each of the 54 streams surveyed as described in the Methods in Chapter two (p. 24).

3.2.2 Laboratory methods

In the laboratory macroinvertebrate samples were rinsed with water through a 250 μm sieve. Individuals were then identified and counted using a binocular stereomicroscope at 10-63 x magnification. The relative abundance of each taxa was defined as the number of individuals of each taxon collected per stream sampled.

Annelida, Nematoda, Nematomorpha, and Platyhelminthes were identified to a phyla level. Amphipoda belonging to the Paracalliopidae family were identified to a genus level using Fenwick (2007), and other Anthropoids (Acari, Cladocera, and Collembola) were identified to a subclass or order level. Isopoda were identified to a genus level based off descriptions by Johns and Fenwick (2007), Ostracoda were identified to a class level, and freshwater shrimp from the family Atyidae were identified to a species level using Chapman et al. (2011). Coleoptera were identified to family and genus levels depending on the taxa using Winterbourn et al. (2006), Smith (2007b), Smith (2007c), Smith (2007d), and Smith (2007e). The identification of the endemic beetle *Orchymontia banksiana* was confirmed by Dr Richard Leschen of Landcare Research in Auckland, to the description of Delgado and Palma (1999) based off the original speciation by Ordish (1984). Diptera were identified to family, genus, or species level where possible using Winterbourn et al. (2006) and Smith (2003). Mollusca were identified to family, genus, or specie levels depending on the taxa using Smith (2007a). Species belonging to the orders Megaloptera and Mecoptera were identified level using Winterbourn et al. (2006). Ephemeroptera were identified to a genus or species level using Winterbourn et al. (2006) and Hitchings and Staniczek (2003). Plecoptera were identified to a species level using Winterbourn et al. (2006), McLellan (1993), McLellan (1999), Veale et al. (2018), and personal communication with B. Foster (2019) (Appendix 1). Trichoptera were identified to a genus level and where possible a species level using Winterbourn et al. (2006), Smith (2001), and Smith (2002).

The total diversity and relative abundance for each stream surveyed was determined by combining the respective microhabitat (riffle, run, pool, and organic) kick net results from each surveyed stream. Microhabitat invertebrate presence/absence data for each stream reach was kept separate for the last section of this chapter, where microhabitat preference is addressed.

3.2.3 Analysis

Three levels of diversity (alpha, beta, and gamma) were tested. Alpha (local) diversity was defined as the number of different taxa collected at each of the 54 streams. Because catchments are small on the Peninsula and I often had only sampled once within a catchment. Consequently, there was not sufficient replication to define Beta diversity by true catchments. Therefore, "pseudo-catchments" were defined based on aspect, similar microclimate, and broad scale vegetation patterns. These "pseudo-catchments" are referred to as "catchments" in this chapter and from west to east are: Te Waihora (TW), Lyttelton (L), Wairewa (W), Northern Outer Bays (OBN), Southern Bays (SB), Akaroa (A), and Eastern Outer Bays (OBE) (Fig. 3.1). Five streams were surveyed in the Southern Bays Catchment and six streams were surveyed in the Te Waihora, Lyttelton, and Northern Outer Bays catchments. Seven streams were surveyed in Wairewa, 11 in Akaroa, and 13 in the Eastern Outer Bays Catchment. Beta (catchment) diversity was defined as the number of different taxa that occurred in each of the seven catchments on Banks Peninsula, as shown in Figure 3.1. Gamma (regional) diversity was calculated as the number of different taxa collected across the Peninsula (all 54 streams across each of the seven catchments). At each level of diversity (alpha, beta, and gamma) the proportion of diversity represented by regionally endemic species was also calculated.

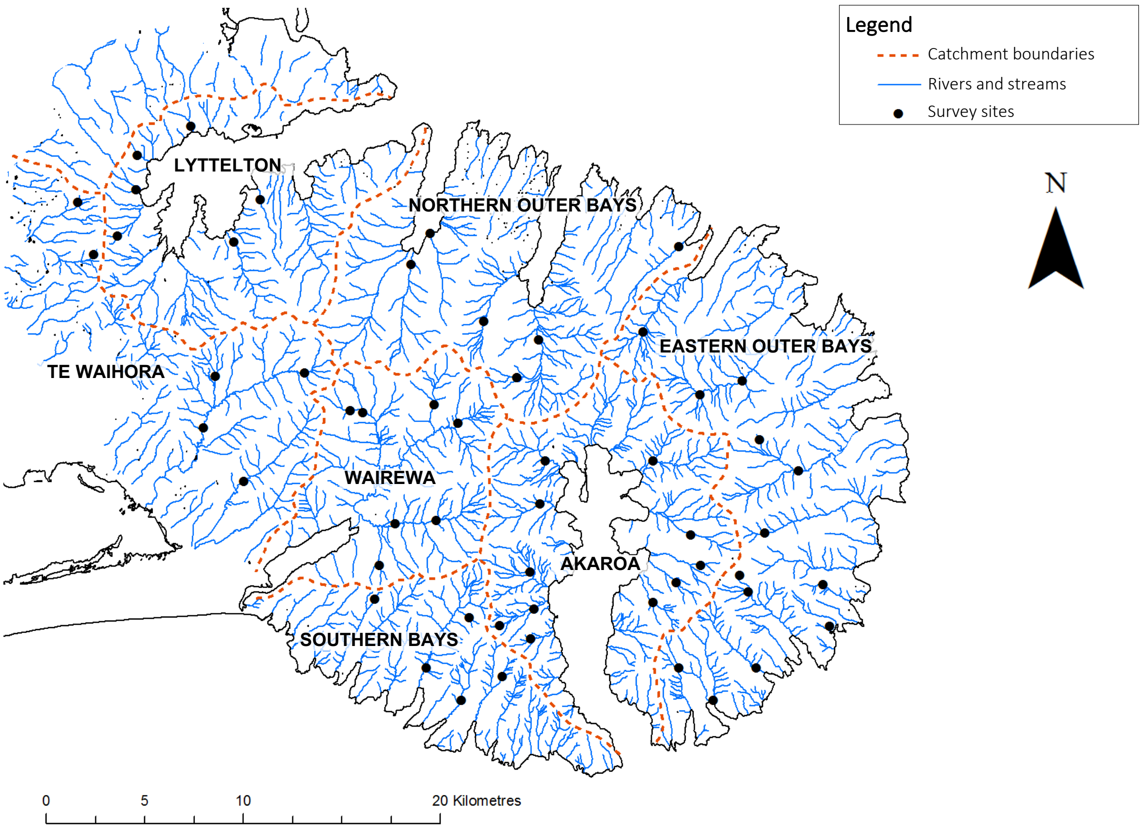


Figure 3.1: Map of the seven pseudo-catchments and the 54 stream locations that were surveyed over the 2018/19 summer on Banks Peninsula.

Additionally, beta diversity was also calculated using the formula $\beta = \gamma/\alpha$ from Whittaker (1960). This was calculated by dividing the regional diversity by the mean local diversity of each catchment. This method allows a comparison of how often the diversity of the region exceeds the average local diversity. Poisson generalised linier models (GLM) and Spearman's rank correlations were used to determine whether there was a significant relationship or correlation between the average catchment value of eight physical variables, five chemical variables, and two geographic parameters (northing and easting) and both beta diversity measures. These physical variables were stream width, channel stability, altitude, native riparian cover, shading, substrate index, stream velocity, and stream depth. The five chemical variables were pH, conductivity, temperature, dissolved oxygen, and turbidity.

Quasi-Poisson GLMs were performed to determine if the mean alpha diversity and relative invertebrate abundance varied significantly between the seven catchments. A Poisson GLM was used to determine whether there was a significant relationship between the number of different regionally endemic species and the alpha diversity of a stream. Quasi-Poisson GLMs were also used to test if there was a relationship between alpha diversity the following 15 variables: stream width, channel stability, altitude, native riparian cover, shading, substrate index, stream velocity, stream depth, pH, conductivity, temperature, dissolved oxygen, turbidity, northing, and easting. Quasi-Poisson GLMs and F-tests were used, opposed to standard Poisson GLMs and Chi squared tests to account for over dispersion.

A constrained correspondence analysis (CCA) was used to test whether eight physical and five chemical variables had a significant linear influence of on the presence/absence of stream invertebrates across the surveyed streams. The CCA was performed using the community ecology R package Vegan, Version 2.5-6 (Oksanen et al., 2019). The CCA was scaled using Hill's Scaling, which rescales of the axis scores to improve ecological interpretation. An ANOVA permutation was carried out to determine if there was a relationship between the stream invertebrate communities and the measured physical and chemical variables. An ANOVA permutation using Type III sums of squares (significances of marginal effects) was used to determine the significance of the relationship between each environmental variable and the community composition of the streams surveyed.

Lastly, 18 taxa were selected to determine if they showed microhabitat preference between riffles, runs, pools, and organic matter. All of the seven regionally endemic species (*Costachorema peninsulae, Hydrobiosis styx, N. chiltoni, Nesameletus vulcanus, O. banksiana, Zelandobius wardi,* and *Zelandoperla* sp. 1) were used, as well as 11 other taxa (*Archichauliodes diversus, A. cyrene, Austrosimulium* spp., *C. humeralis, Deleatidium* spp., *Nannochorista philpotti, P. antipodarum, Pycnocentria evecta, Pycnocentria* sp. A*, Zelandoperla decorata,* and *Zephlebia* spp.) which were commonly collected or have shown microhabitat preferences in other studies. Combined, a total of 202 riffle, run, pool, and organic microhabitats were surveyed across 54 streams on the Peninsula. Binomial generalised linier models were used to determine if the proportion of occurrence of these 18 taxa differed significantly across the four microhabitats.

3.3 RESULTS

3.3.1 Regional diversity (γ) and structure

A total of 95 taxa were collected across the Banks Peninsula Ecoregion (gamma diversity). Regionally endemic species made up 7 % of the invertebrate diversity and accounted for 5 % of the abundance of invertebrates collected. Caddisflies (Trichoptera) were the most diverse order, with 32 taxa. Two-winged flies (Diptera) were the second most diverse order with 22 taxa, followed by mayflies (Ephemeroptera) with 9 taxa, beetles (Coleoptera) with 7 taxa, stoneflies (Plecoptera) with 7 taxa, and Mollusca (5 taxa). Additionally, 13 taxa from other orders were also collected. Twenty-six taxa were recorded at ≥ 50 % of the streams surveyed and 25 taxa were collected from less than five streams. The most commonly occurring invertebrates were the mayfly *Deleatidium* spp. and dipteran Orthocladiinae, which were collected from 98 % of my streams. Early instars of the free-living caddisfly *Hydrobiosis* spp. and the cased-cased *Olinga* spp. were the most common caddisfly taxa, collected at 83 % and 81 % of the streams, respectively. The most commonly occurring mayflies were *Deleatidium* spp. and *C. humeralis,* which occurred at 98 % and 80 % streams, respectively. The two most common stoneflies, *A. cyrene* and *Z. decorata* occurred at 48 % and 44 % of streams, respectively.

Two-winged flies and snails were the two most abundant invertebrates, making up 26 % and 22 % of the invertebrates collected. Mayflies were the third most abundant, accounting for 21 % of the individuals collected in this study. This is high compared to the diversity of mayflies, which only represents 9 % of the diversity (Fig. 3.2). Despite caddisflies being the most diverse order, they only represented 22 % of the total relative abundance (Fig. 3.2). Other taxonomic groups (Arci, Annelida, Cladocera, Collembola, Crustacea, Megaloptera, Mecoptera, Nematoda, Nemotomorpha, and Platyminthes) made up only 5 % of the abundance, while stoneflies and beetles represented just 2 % and 1 % of the total invertebrate relative abundance (Fig. 3.2b).

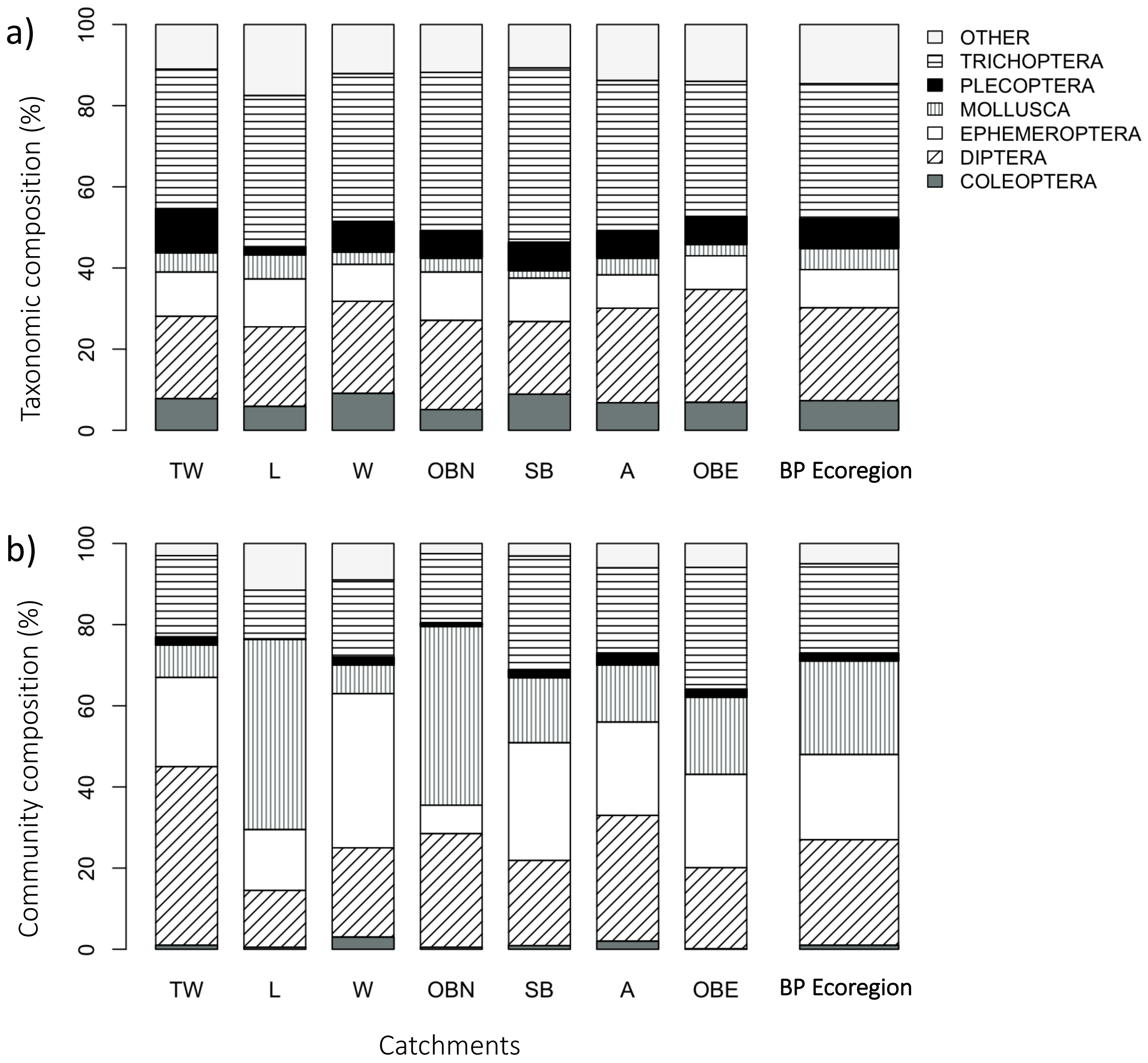


Figure 3.2: Stream invertebrate composition across seven catchments and the entire Banks Peninsula Ecoregion. Where, taxonomic composition (a) and community composition (b), is shown for each of the seven catchments and for the Banks Peninsula Ecoregion (BP Ecoregion). Taxonomic composition shows the number of different taxa in each order as a percentage and community composition shows the relative abundance of taxa across the main orders as a percentage. Catchments are shown from west to east and are as follows: Te Waihora (TW, n=6), Lyttelton (L, n=6), Wairewa (W, n=7), Northern Outer Bays (OBN, n=6), Southern Bays (SB, n=5), Akaroa (A, n=11), and Eastern Outer Bays (OBE, n=13).

3.3.2 Pseudo-catchment diversity (β) and structure

Beta diversity ranged between 72 and 51 taxa across the seven catchments (Table 3.1). Beta diversity was highest in the Akaroa and Eastern Other Bays catchments, where 72 different taxa were collected. Beta diversity was lowest in Lyttelton where only 51 taxa were collected (Table 3.1). Whittaker (1960) diversity, which compares the ratio of regional diversity to local diversity ($\beta = \gamma/\alpha$), showed a similar pattern as the standard β diversity values. However, the mean local diversity was lower than the regional diversity in all catchments (Table

3.1). Lyttelton has the highest ratio between the regional and local diversity, the next highest catchments are Southern Bays and Te Waihora, followed by Eastern Outer Bays and Northern Outer Bays (Table 3.1). Akaroa and Wairewa had the lowest ratio (Table 3.1). Endemic species accounted for between 4-11 % of the diversity in the catchments and between 1-15 % of the relative abundance of invertebrates (Table 3.1).

Table 3.1: Beta diversity of the seven pseudo-catchments on the Peninsula and the representation of regionally endemic species in these catchments.

Catchment	β diversity (no. of taxa per catchment)	β diversity Whittaker ($\beta = \gamma/\alpha$)	Percent of diversity attributed to regionally endemic spp.	Percent of relative abundance attributed to regionally endemic spp.
Te Waihora	64	3.4	11 %	2 %
Lyttelton	51	5.6	4 %	1 %
Wairewa	66	2.8	9 %	15 %
Northern Outer Bays	59	2.9	8 %	2 %
Southern Bays	56	3.4	11 %	5 %
Akaroa	72	2.8	10 %	11 %
Eastern Outer Bays	72	3.1	8 %	5 %

As far as environmental variables are concerned, there was no significant relationship or correlation between the majority of the mean physical, chemical, and geographic variables of the streams in each catchment and the standard beta diversity or Whittaker diversity (Table 3.2). Only two variables showed some correspondence with the beta diversity measures. The mean stream depth per catchment was found to have a significant relationship with beta diversity (no. of taxa per catchment), while the mean stream velocity was found to have a significant relationship with Whittaker diversity ($\beta = \gamma/\alpha$) (Table 3.2).

The taxonomic composition was similar between the seven catchments (Fig. 3.2a). However, stonefly diversity was particularly low in Lyttelton, where they only accounted for 2 % of the catchment's diversity. Community composition showed a consistent pattern across the Wairewa, Southern Bays, Akaroa, and Outer Bays East catchments (Fig. 3.2b). However, the two-winged flies (Diptera) represented a higher proportion of the abundance in Akaroa and in the Eastern Outer Bays Catchment beetle abundance was very low (< 1 %). Two-winged flies were extremely abundant in Te Waihora, accounting for 44 % of the abundance (Fig. 3.2b). Mollusca were abundant in Lyttelton and the Northern Outer Bays, where they accounted for 47 % and 44 % of the relative abundance, respectively (Fig. 3.2b).

Table 3.2: Statistical results for the mean catchment physical, chemical, and geographic variables and their relationship to two measures of beta diversity. Where, the relationship between β diversity (no. of taxa per catchment) and the mean variables of each catchment was determined using Poisson generalised linier models. The correlation between β diversity Whittaker (β = γ/α) and the mean variables of each catchment was determined using Spearman's correlation rank tests.

Variables	β diversity (no. of taxa per catchment) df = 1, 5		β diversity Whittaker (β = γ/α)	
Physical variables	χ^2 value	p value	Correlation coefficient	p value
Stream width	1.77	0.18	-0.69	0.09
Channel stability	0.05	0.82	0.25	0.58
Altitude	0.27	0.60	0.20	0.68
Native riparian cover	0.64	0.42	-0.07	0.88
Shading	0.05	0.82	0.40	0.37
Substrate index	0.45	0.50	0.51	0.24
Stream velocity	2.98	0.08	**-0.91**	**<0.01**
Stream depth	**4.88**	**<0.05**	-0.74	0.06
Chemical variables				
pH	0.02	0.87	-0.25	0.58
Conductivity	0.05	0.83	0.49	0.26
Temperature	0.09	0.77	-0.36	0.42
Dissolved oxygen	2.09	0.15	0.12	0.82
Turbidity	0.22	0.64	-0.82	0.02
Geographic parameters				
Northing	1.60	0.21	0.33	0.47
Easting	2.71	0.10	-0.56	0.19

3.3.3 Local stream diversity (α) and structure

Alpha diversity ranged from 8 to 46 taxon across the streams. The most diverse stream was in the head waters of the Wairewa Catchment (stream 14-W), while the lowest diversity was recorded in the north of Lyttelton Catchment (5-L). Alpha diversity was found to differ significantly between stream order ($F_{3, 50}$=11.10, p=<0.001) and generally increased with stream order (Fig. 3.3). Local diversity varied significantly across seven catchments ($F_{6,47}$= 4.53, p<0.001) (Fig. 3.4a). The streams surveyed in the Akaroa and Wairewa catchments had the highest mean diversity, of 34 ± SE 2 and 34 ± SE 3, respectively. Streams in the Lyttelton Catchment had the lowest diversity, with an average diversity of just 19 ± SE 4. The abundance of invertebrates collected at each of the streams surveyed did not differ significantly across the catchments ($F_{6,47}$= 1.99, p=0.09) (Fig. 3.4b).

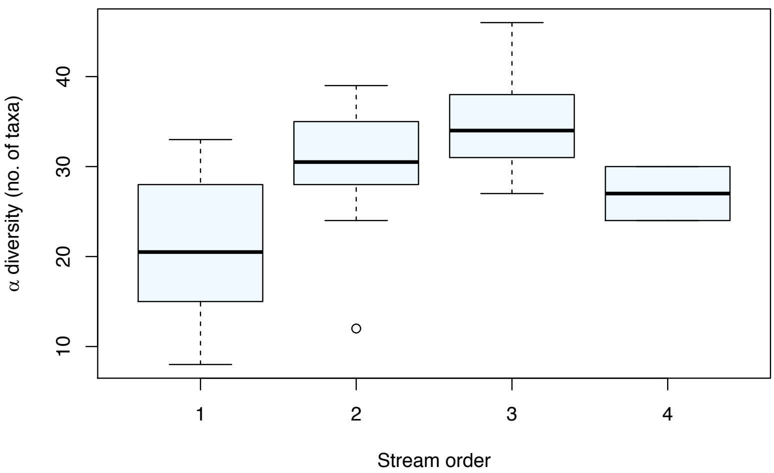


Figure 3.3: Relationship between alpha diversity and stream order. Error bars and outlying data points represent the maximum and minimum values for each catchment. Ten 1st order, 20 2nd order, 22 3rd order, and two 4th order streams were surveyed across the Peninsula.

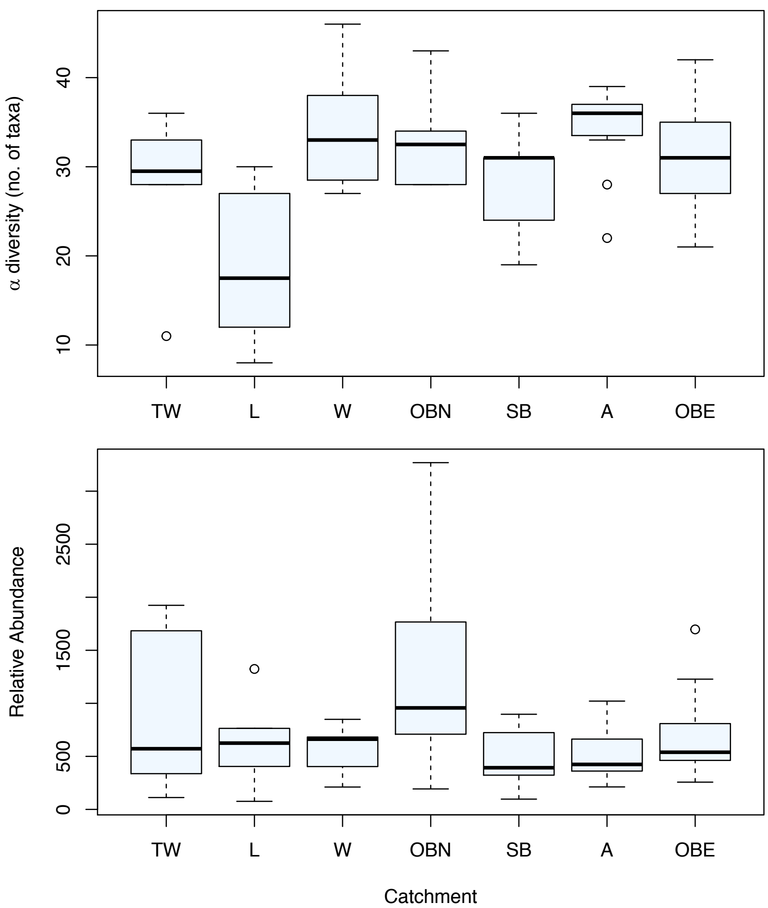


Figure 3.4: The median alpha diversity (a) and median relative abundance (b) the of streams surveyed from each of the seven catchments. Catchments are listed from west to east and are as follows: Te Waihora (TW, n=6), Lyttelton (L, n=6), Wairewa (W, n=7), Northern Outer Bays (OBN, n=6), Southern Bays (SB, n=5), Akaroa (A, n=11), and Eastern Outer Bays (OBE, n=13). Error bars and outlying data points represent the maximum and minimum values for each catchment.

3.3.4 Patterns in regionally endemic species

Across the 54 streams surveyed, regionally endemic stream invertebrates accounted for between 0-21 % of the local diversity. In almost half (46 %) of the streams, endemic invertebrates represented > 10 % of the local diversity. However, in 26 % of the streams surveyed endemic species represented < 5 % of the diversity. There is a significant (χ^2=43.9, df= 1, 52, p<0.001) relationship between the number of different endemic species present and local diversity (Fig. 3.5). Therefore, as the number of different regionally endemic species increases in a stream, the total diversity (or alpha diversity) of the streams is also expected to increase (Fig. 3.5).

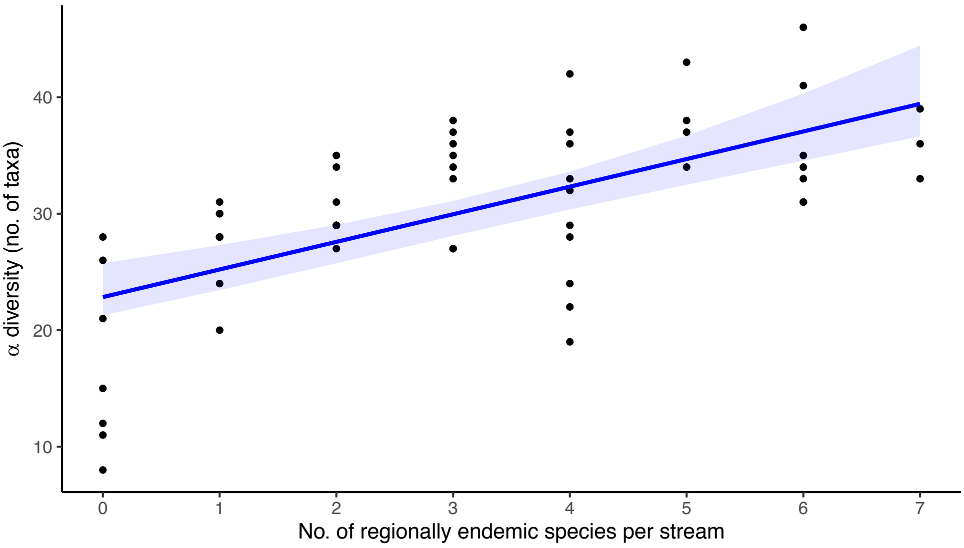


Figure 3.5: Relationship between the number of different regionally endemic stream invertebrate species per stream and alpha (local) diversity. Each black point represents one of the 54 survey streams. The blue line and shaded band represent the generalised linear model output and 95 % confidence intervals, respectively.

3.3.5 Influence of physical and chemical conditions on alpha diversity

There is a significant linear correlation between stream width, stream velocity, stream depth, conductivity, and dissolved oxygen (Fig. 3.6 and Table 3.3). Alpha diversity increases on the Peninsula as streams widen, deepen, increase in velocity and as dissolved oxygen increases (Fig. 3.6). However, alpha diversity is negatively correlated with conductivity (Fig. 3.6d). Stream diversity increases towards the east (easting) and south (northing) of the Peninsula (Table 3.3 and Fig. 3.6 f and g). There is no correlation between alpha diversity and stream shading, native vegetation cover, altitude, channel stability, substrate size, pH, temperature, and turbidity (Table 3.3).

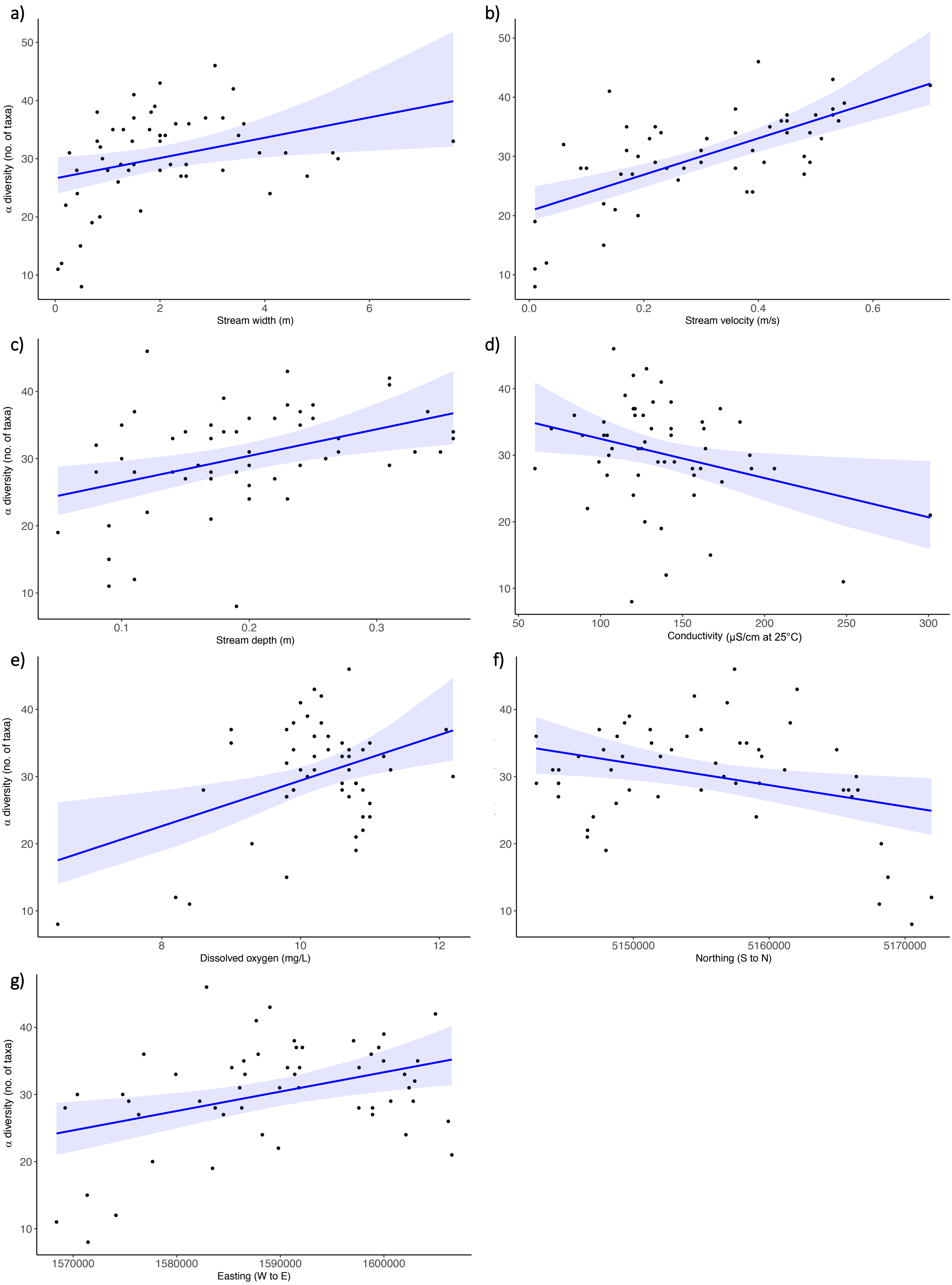


Figure 3.6: The statistically significant correlations between alpha diversity and physico-chemical parameters of 54 streams surveyed on Banks Peninsula and stream width (a), stream velocity (b), stream depth (c), conductivity (d), dissolved oxygen (e), easting (f), and northing (g). The blue line and shaded band represent the generalised linear model output and 95 % confidence intervals, respectively.

Table 3.3: Generalised linear model results for physical, chemical, and geographic variables and their relation to alpha diversity. Over-dispersion in the models was accounted for by using Quasi-Poisson modelling.

Variables		df	F-ratio	p value
Physical variables				
	Stream width	**1, 52**	**6.33**	**<0.05**
	Channel stability	1, 52	0.30	0.57
	Altitude	1, 52	0.05	0.83
	Native riparian cover	1, 52	0.25	0.62
	Shading	1, 52	0.04	0.85
	Substrate index	1, 52	0.97	0.33
	Stream velocity	**1, 52**	**34.96**	**<0.001**
	Stream depth	**1, 52**	**9.52**	**<0.01**
Chemical variables				
	pH	1, 52	3.22	0.08
	Conductivity	**1,52**	**5.66**	**<0.05**
	Temperature	1, 52	2.77	0.10
	Dissolved oxygen	**1, 52**	**9.70**	**<0.01**
	Turbidity	1, 52	1.27	0.27
Geographic parameters				
	Northing	**1, 52**	**6.12**	**<0.05**
	Easting	**1, 52**	**9.16**	**<0.01**

3.3.6 Community structure and composition

CCA analysis showed that the 13 measured environmental variables have a significant ($F_{13, 38}$=1.46, p<0.001) influence on the community composition of stream invertebrates across the Peninsula (Fig. 3.7a). This CCA model explains 33 % of the variation in the community composition. Two of variables were found to have a significant linear relationship with the stream invertebrate community. These variables were altitude ($F_{1,40}$=1.44, p <0.05) and stream shading ($F_{1, 40}$ =1.57, p<0.05). Both variables were the main drivers of horizontal (x-axis) separation along with temperature, pH, and channel instability (Fig. 3.7a). Conductivity along with variables that are related to stream size (stream width, velocity, and depth) influenced vertical (y-axis) separation of the invertebrate communities (Fig. 3.7a).

Commonly occurring taxa such as *Austrosimulium* spp., Tanypodinae, *P. antipodarum*, *C. humeralis,* and *Olinga* spp. showed little association with the different environmental variables (Fig. 3.7b). In contrast, rarer taxa such as *Z. wardi, Zelandoperla* sp. 1*, N. vulcanus, N. philpotti,* and *Stenoperla prasina* were strongly associated with higher levels of stream shading, native riparian vegetation, altitude, and substrate index (Fig. 3.7b). The presence of other regionally endemic species, such as *C. peninsulae, O. banksiana,* and *N. chiltoni* were associated with variables such as stream width, velocity, depth, and higher levels of dissolved oxygen. Two common caddisflies, *Neurochorema confusum* and *P. evecta* were more tolerant of warmer and wider streams (Fig. 3.7b). The occurrence of the mosquito (Culicidae) *Culex* spp. and the isopod *Austrisotea* sp. A at two separate streams (1-L and 54-OBE, respectively) caused the community composition of these streams to diverge from the other streams surveyed (Fig. 3.7a).

Invertebrate communities collected from poorly shaded streams were also likely to be from wider and warmer streams with higher channel instability (Fig. 3.7a). A number of these variables (shading, channel instability, width, and temperature) are correlated (Appendix 3), meaning they commonly occur together. Other variables are also correlated such as altitude, shading, and native vegetation (Appendix 3). Therefore, on the Peninsula there is more native vegetation and stream shading at higher altitudes, where streams are narrower. Dissolved oxygen is not associated with altitude or stream size (Appendix 3). Thus, meaning that smaller, steeper streams with more cascades do not show higher levels of dissolved oxygen on the Peninsula. It is possible that there is no association between dissolved oxygen and altitude on the Peninsula as streams near the coast and in the centre of the Peninsula can both be extremely steep.

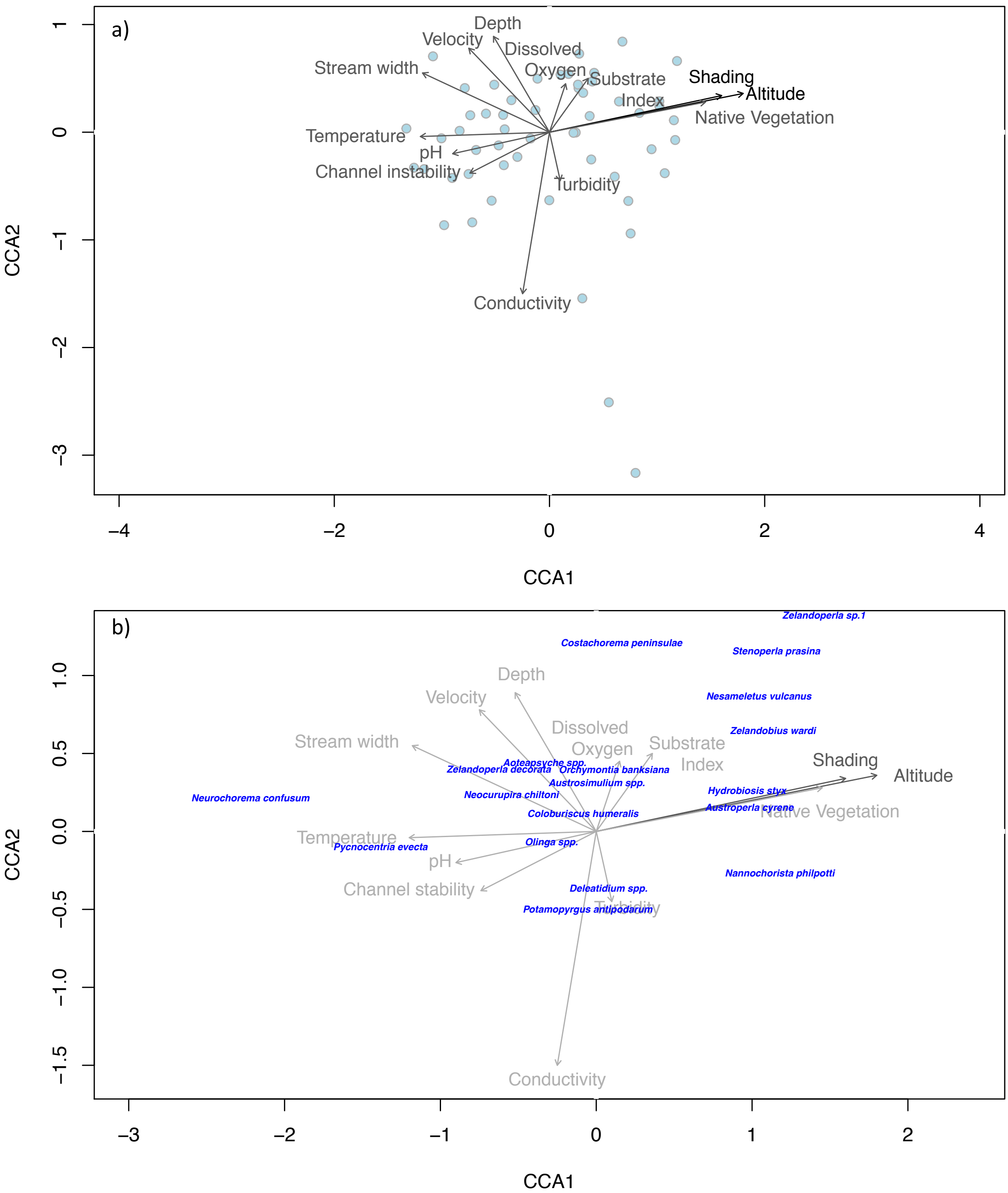


Figure 3.7: Constrained correspondence analysis (CCA) ordination showing the relationship between Banks Peninsula's stream invertebrate community and 13 environmental variables. Where a) shows the relationship between the 54 stream communities surveyed and b) shows the relationship between the environmental variables and some of the 95 different taxa collected on the Peninsula. Arrow length represents the influence of each of the 13 continuous environmental variables has on the invertebrate community and arrow direction shows separation of stream communities. Variables in grey were statistically insignificant and the variables in black (altitude and shading) were found to be significant. Blue points represent the different stream invertebrate communities collected from the 54 survey streams and taxon are shown in blue text.

3.3.7 Macrohabitat patterns

Diversity across the four microhabitats (riffles, runs, pools, and organic matter) was similar. Organic matter microhabitats had the highest diversity with 78 taxa, followed by runs with 71 taxa, while pools and riffles had the same diversity, with 70 taxa. Of the seven regionally endemic species, all species except *C. peninsulae* and *Zelandoperla* sp. 1, were collected from all four of the microhabitats (Fig. 3.8). *C. peninsulae* and *Zelandoperla* sp. 1 were not collected from pool habitats (Fig. 3.8).

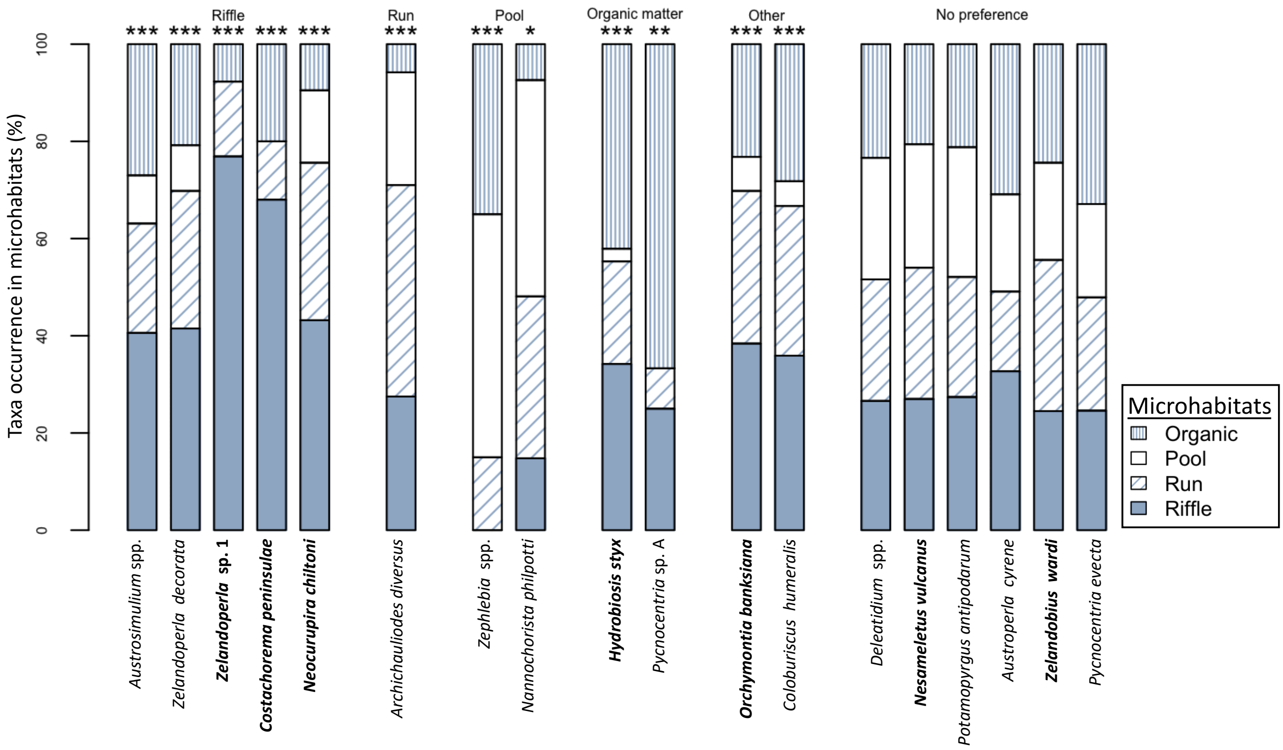


Figure 3.8: Occurrence of taxa collected on Banks Peninsula across four different microhabitats (riffles, runs, pools, and organic matter) shown as a percentage. From right to left taxa are grouped by preference to riffles, runs, pools, organic matter, other preference, and no preference. Asterisks at the top of each taxa's column represent the presence and level significant differences between that taxa's occurrence across the four different microhabitats. Where, p values <0.05* are significant, <0.01** are very significant, and <0.001*** are highly significant. This statistical data is shown in Table 3.4. Species shown in bold are regionally endemic to Banks Peninsula.

Of the 18 different taxa assessed for microhabitat preference, the occurrences of 12 taxa differ significantly across the four microhabitats (Table 3.4 and Fig. 3.8). Five taxa (*Austrosimulium* spp.*, Z. decorata, Zelandoperla* sp. 1, *N. chiltoni,* and *C. peninsulae*) favoured riffle environments and rarely occurred in pool habitats (Table 3.4 and Fig. 3.8). *A. diversus* was most commonly collected from run habitats and rarely occurred in organic matter. Both *Zephlebia* spp. and *N. philpotti* showed preference towards slow flowing pool habitats. However, *Zephlebia* spp. were never collected in riffles and *N. philpotti* were rarely collected from organic matter. *H. styx* and *Pycnocentria* sp. A showed strong preference to organic matter environments and rarely or never occurred in pools. Two species *O. banksiana* and *C. humeralis* did not occur at different proportions across riffle, run, and organic habitats, but were rarely collected from pools (Table 3.4 and Fig. 3.8). Lastly, six taxa showed no habitat preference and occurred at similar proportions across the four different microhabitats (Table 3.4 and Fig. 3.8).

Table 3.4: Results from generalised linier models showing the relationship between the proportion of occurrence (presence or absence) of different taxa collected from four microhabitats (riffle, run, pool, and organic matter) on Banks Peninsula in the 2018/19 summer. A total of 202 microhabitats were sampled across 54 streams. Species marked with an asterisk are regionally endemic.

Order	Taxa	χ^2 (df= 3, 198)	p value
COLEOPTERA	***Orchymontia banksiana**	**37.32**	**<0.001**
DIPTERA	***Austrosimulium* spp.**	**51.41**	**<0.001**
	***Neocurupira chiltoni**	**34.21**	**<0.001**
EPHEMEROPTERA	***Coloburiscus humeralis***	**70.27**	**<0.001**
	Deleatidium spp.	3.11	0.38
	**Nesameletus vulcanus*	0.74	0.86
	***Zephlebia* spp.**	**16.16**	**<0.001**
MEGALOPTERA	***Archichauliodes diversus***	33.24	**<0.001**
MECOPTERA	***Nannochorista philpotti***	**10.62**	**<0.05**
MOLLUSCA	*Potamopyrgus antipodarum*	2.01	0.57
PLECOPTERA	*Austroperla cyrene*	6.19	0.10
	**Zelandobius wardi*	2.02	0.57
	Zelandoperla decorata	**16.50**	**<0.001**
	***Zelandoperla* sp. 1**	**19.12**	**<0.001**
TRICHOPTERA	***Costachorema peninsulae**	**30.86**	**<0.001**
	***Hydrobiosis styx**	**22.20**	**<0.001**
	Pycnocentria evecta	6.21	0.10
	***Pycnocentria* sp. A**	**15.08**	**<0.01**

3.4 DISCUSSION

3.4.1 Stream invertebrate diversity

Banks Peninsula's stream invertebrate fauna is highly diverse. The dominance of Diptera and Trichoptera in the Peninsula's streams is consistent with the findings of Harding and Winertbourn (1997) and Harding (2003). In this study 95 taxa were collected across the ecoregion, to my knowledge this is the most extensive study assessing the benthic diversity of Banks Peninsula streams. Banks Peninsula's diversity is comparable to other larger ecoregions such as Northland, Taranaki, and Westland where between 90 and 119 taxa have been recorded (Boothroyd, 2000). Another study comparing the diversity of stream invertebrates across all of New Zealand's ecoregions showed that Banks Peninsula was the fifth most diverse ecoregion in the country (Harding and Winertbourn, 1997), suggesting that the high level of regional diversity seen in this study is not unusual. These high levels of diversity indicate that Banks Peninsula has a diverse range of stream environments and at least some streams are in pristine condition.

Beta diversity across the Peninsula's catchments differed by more than 20 taxa between the most and least diverse catchments. In New Zealand, beta diversity has been suggested to increase from north to south (Astorga et al., 2014). However, at the smaller regional scale of Banks Peninsula there was no statistical relationship between beta diversity and northing or easting. The absence of a geographic pattern of beta diversity on the Peninsula is possibly because the Peninsula is a relatively small land mass, which has been significantly altered by humans. The catchments used to define beta diversity in this study are much closer in proximity and smaller than the regions used to define beta diversity in other studies (e.g. Astorga et al. (2014)). Beta diversity did show a weak correlation with stream velocity and stream depth (Table 3.2), suggesting that catchments with larger and faster flowing streams were more diverse. This is consistent with the diversity patterns observed locally on the Peninsula. However, these beta diversity catchment scale patterns were weak and primarily driven by the occurrence of small low flowing streams with low diversity in the Lyttelton Catchment. Furthermore, catchments with larger stream networks, tend to have more permanent streams that can support invertebrates year-round.

It is possible that the difference in beta diversity across the Peninsula was driven by larger landscape variation, rather than the parameters measured locally in this study. Many of the physical variables I measured varied considerably within each of the catchments. For example, in the Eastern Outer Bays Catchment, streams were surveyed in both dense native bush and unshaded pastural land. Therefore, there was considerable variation in vegetation and shading within the Eastern Outer Bays Catchment. The low beta diversity of the Lyttelton Catchment was probably driven by larger scale landscape differences (e.g. urbanisation and forest). For example, the high Whittaker β diversity value for the Lyttleton Catchment is driven by the low local diversity of three small urbanised streams on the northern side of Lyttelton Harbour. I would expect patterns of beta diversity to become clearer on the Peninsula if habitat measurements were assessed at a catchment scale (e.g. proportion of native vegetation cover per catchment).

Local diversity varied widely across the 54 different streams, but was higher in wider, faster flowing, deeper, and higher order streams (Fig. 3.3 and 3.6). I expected this because of the wider range of habitat heterogeneity in these streams, promoting different niches for invertebrates. However, there is only a hand full of large streams on the Peninsula, as the majority of streams in the region are small (< 4 m wide). It is also possible that more diverse headwater streams are facilitating diversity in larger stream at the bottom of catchments. For example, streams in the headwaters of the Kaituna Valley were well forested and had high local diversity, which maybe promoting diversity in the larger lowland areas of the stream.

Conductivity was found to be correlated with stream diversity. However, this relationship seems to be driven by several outlying readings of high conductivity, which occurred in either very slow flowing streams or streams in close proximity to the coast. Sea spray and possibly sedimentation may be causing these streams to have higher levels of dissolved ions, thus combined with other factors such as stream permanence have reduced the diversity in these streams. In general conductivity was high in the Peninsula's streams. However, this and other water chemistry results (e.g. pH) were consistent with the findings of Harding and Winertbourn (1997), where sea spray was suggested to be a cause of high conductivity.

Some of the strongest predictors of local diversity on the Peninsula were geographic parameters (Fig. 3.6 f and g). Stream invertebrate diversity increases towards the east and south on the Peninsula as hypothesised. Therefore, streams in the southeast of the Peninsula have some of the highest localised levels of diversity. The northern and western areas of Banks Peninsula are drier, have less native forest, smaller stream networks, and more agricultural land compared to the rest of the Peninsula. Streams with less shading are known to have lower levels of diversity in New Zealand (Death and Collier, 2010) and stream reaches in agricultural land on Banks Peninsula have lower taxonomic richness compared with forested streams (Harding, 2003). These studies suggest that diversity should be higher in areas of the Peninsula that have more forest, such as the Southern Bays and Eastern Outer Bays catchments. The absence of a statistical relationship between shading and/or native vegetation and local diversity in this study may be due to forest fragmentation. Most of the streams surveyed in this study were either within regenerating native forest or in open unshaded agricultural land. Therefore, the majority of the streams surveyed in this study either had very high or low levels of shading and native riparian vegetation, meaning very few streams were sampled with mediocre levels of native or shade cover. Furthermore, some well-established forested reaches were below open unshaded agricultural land (e.g. Hay Scenic Reserve, Pigeon Bay) and other stream reaches surveyed have only been recently been planted or have begun to regenerate native vegetation (e.g. Koukourārata Stream, Port Levy). Therefore, despite the high amounts of forest regeneration on the Peninsula, some low diversity streams in areas with high native riparian vegetation cover, particularly in the lowlands may still be reflecting the impacts historic land use.

Other studies investigating the diversity of stream invertebrates have suggested that forested streams contain some of the highest levels of diversity (e.g. Death and Collier (2010)). Many of the streams surveyed in established forested in this study were small headwaters. Despite these small forested headwaters not showing high levels of diversity, well shaded streams and forested streams at high altitudes promoted the occurrence of a suite of forest loving taxa, that rarely occurred in other stream environments on the Peninsula (Fig. 3.7b). Therefore, small forested headwaters on the Peninsula are still an important contributor to the Peninsula's diversity.

3.4.2 Stream invertebrate communities

Regardless of environmental and hydrological characteristics of the streams on Banks Peninsula, a common core group of invertebrates occurred across the streams surveyed (Fig. 3.7). Many of these common taxa such as *Deleatidium*, *Coloburiscus, Hydrobiosis*, *Aoteapsyche*, *Olinga, Austrosimulium,* and *Potamopyrgus* are common throughout New Zealand's streams (Boothroyd, 2000, Winterbourn et al., 2006). Two regionally endemic taxa (*N. chiltoni* and *O. banksiana*) were also common in streams on the Peninsula and therefore are also driving community similarity between the surveyed streams. However, other stream invertebrates collected on the Peninsula were more closely associated with environmental factors.

The occurrence of stream invertebrates and community composition on the Peninsula was primarily driven by shading and altitude (Fig. 3.7b). Therefore, shading and altitude seem to control the absence and presence of uncommon taxa on the Peninsula. In poorly shaded streams at low altitudes sensitive taxa such as *A. cyrene* were absent. Instead in these larger lowland streams, with less shading and native riparian vegetation had tolerant taxa such as *N. confussum, Hydrobiosis parumbripennis* and *P. evecta*. These species are known to be common in unshaded or open larger stony streams (Winterbourn et al., 2006). On the other hand, streams with higher levels of shading and native riparian vegetation cover at higher altitudes had more sensitive taxa, such as *S. prasina, A. cyrene, N. philpotti,* and several regionally endemic species (Fig. 3.7b). This suggests that shading and altitude variation are important drivers of different stream invertebrate communities on the Peninsula. The variation in shading and altitude also seems to be particularly important for the regionally endemic species, which tend to occur in two main community groups. *N. chiltoni, O. banksiana,* and *C. peninsulae* are characteristic of communities that occur in wider less shaded streams, while *H. styx, N. vulcanus, Z. wardi,* and *Zelandoperla* sp. 1 prefer streams with more native vegetation and shading at higher altitudes (Fig. 3.7b).

Excluding the regionally endemic species, none of the other stream invertebrates collected on the Peninsula are considered to be 'threatened' or 'at risk' based off the New Zealand Threat Classification of freshwater invertebrates (Grainger et al., 2018). However, some of the taxa considered 'not threatened', are uncommon in New Zealand streams. For example, *N. philpotti* were frequently collected from forested streams on the Peninsula. However, their specific preferences to the backwaters of small forested streams in the South Island (Winterbourn et al., 2006), means they are uncommon in many streams on the Canterbury Plains and over the wider South Island (J. Harding, personal communication, 2019).

Although 95 taxa were collected in this study, some orders, families, and taxa of New Zealand's freshwater invertebrate fauna were absent on the Peninsula. No Odonata (damselfies or dragonflies) or Hemiptera (water bugs) were collected on the Peninsula. Presumably these orders are absence because they prefer slow flowing streams and stream backwaters, which rarely occur on Banks Peninsula, or pond and lake environments (Winterbourn, 2000, Winterbourn et al., 2006), which were not sampled in this study. Lacewings (Neuroptera) were not collected, despite their broad distribution in New Zealand. Lacewings were likely missed in the standard kick net sampling used in this study, as they prefer stream margins and waterfall spray zones (Winterbourn et al., 2006). Freshwater beetle diversity on the Peninsula was low. Although, diving beetles (Dytiscidae), water scavenger beetles (Hydrophilidae), and feather-winged beetles (Hydraenidae) were all collected on the Peninsula, some common Canterbury taxa were absent on the Peninsula due to their preference to ponds (e.g. *Huxelhydrus*) and other common beetles such as Elmidae rarely occurred (Winterbourn et al., 2006).

Some widely distributed mayfly genera were not collected on the Peninsula, such as *Ameletopsis, Mauiulus,* and *Oniscigaster,* despite previously being recorded in Canterbury streams (Wright-Stow, 2001, Pohe, 2019). These genera may not occur on the Peninsula due to geographical isolation and habitat preferences or could have been missed in sampling, as *Ameletopsis* are widely dispersed but uncommon (Winterbourn et al., 2006). No stoneflies from the family Notonemouridae were recorded on the Peninsula, despite commonly being collected in the Canterbury foothill streams (J. Harding, personal communication, 2019). The most likely explanation of the absence of Notonemouridae is the geographic isolation of Banks Peninsula. However, taxa from the other three stonefly families (Austroperlidae, Eustheniidae, and Gripopterygidae) are present on the Peninsula. Taxa from 10 different caddisfly families were collected on the Peninsula. The caddisfly families that were not represented on the Peninsula have restricted geographic ranges, such as Kokiriidae, which only occur in northwest Nelson (Winterbourn et al., 2006).

3.4.3 Macrohabitat preference

Many of New Zealand's stream invertebrates have specific adaptations for particular instream environments. Of the 18 taxa investigated in this study, six taxa showed no microhabitat preference. These taxa (*Deleatidium* spp., *N. vulcanus, P. antipodarum, A. cyrene, Z. wardi,* and *P. evecta*) occurred in a broad range of microhabitats, from faster velocity riffles, to pools, and organic substrates such as leaves and macrophytes. The lack of habitat preference shown by *P. antipodarum* and *Deleatidium* spp. is consistent with the findings of Jowett et al. (1991). However, if the life stage or particular species of *Deleatidium* were determined on the Peninsula, the mayfly may show more partitioning between the microhabitats. For example, Jowett and Richardson (1990) have shown that different *Deleatidium* species and life stages prefer different substrate sizes and velocities. The lack of microhabitat preference shown by *A. cyrene* was unexpected. *A. cyrene* are shredders and are known to be common on wood and amongst leaf packs in streams (McLellan, 1997). Therefore, they were expected to show some preference to organic matter. There has been no previous research into microhabitat preferences of the regionally endemics *Z. wardi* and *N. vulcanus.* A study on Banks Peninsula by Linklater (1995) found that *Zelandobius confusus* were associated with leaf lifter as they are shredder species. However, the preference of other *Zelandobius* species, particularly those belonging to the *confusus*-group like *Z. wardi,* suggests they can commonly be collected from stony streams, leaf packs, and wood debris (McLellan, 1993, Winterbourn et al., 2006). Therefore, *Zelandobius* are unlikely show macrohabitat preference. Literature suggests that there is little microhabitat preference shown by *Nesameletus*, as the genera are found from fast flowing mountain streams to lowland streams (Hitchings and Staniczek, 2003, Winterbourn et al., 2006). Jowett et al. (1991) did find that *Nesameletus* spp. showed some preference to large substrates and moderate velocities. However, most of the Peninsula's streams have large substrates and often flow at moderate velocities due to the steep nature of the streams, which may explain why in this study they were found throughout the different microhabitats. The lack of microhabitat preference shown by *P. evecta* is consistent with the common and wide distribution of the species across macrophytes and stony substrates as suggested by Biggs and Malthus (1982) and Winterbourn et al. (2006).

Two other taxa (*C. humeralis* and *O. banksiana*) showed little microhabitat preference between riffle, run, and organic habitats, but rarely occurred in pools. This finding suggests that both species require faster flowing waters, but do not mind living amongst organic matter if water flows are sufficient to sustain resources to the filter feeding *C. humeralis*. The nymphs of *C. humeralis* inhabit the underside of rocks (McNabb, 2002), suggesting they would have easily been collected in this study when rocks were disturbed when organic microhabitats, riffles, and runs were sampled. Hydraenidae are commonly collected from under rocks in fast flowing waters, amongst leaf litter (Ordish, 1984), and in mossy splash zones (R. Leschen, personal communication, 2019). Therefore, it does not seem unusual that the *O. banksiana* collected in this study were from a range of microhabitats.

Three regionally endemic species (*Zelandoperla* sp. 1, *C. peninsulae,* and *N. chiltoni*) and two other taxa (*Austrosimulium* spp. and *Z. decorata*) showed strong preferences towards riffle habitats (Fig. 3.8). Although all of these taxa occurred in riffles, runs, and organic matter, they rarely or never occurred in pools. Two of the endemic species (*Zelandoperla* sp. 1 and *C. peninsulae*) were never collected from pools, suggesting they have become well adapted to the faster flowing sections of Banks Peninsula's streams. The preference of both *Zelandoperla* species to faster flowing stream environments is consistent with the findings of Jowett et al. (1991). Jowett et al. (1991) found that the stonefly genera was associated with large substrates and fast velocities. Furthermore, McLellan (1999) reported that *Zelandoperla pennulata* nymphs (now thought to be the regionally endemic species *Zelandoperla* sp. 1) were collected from waterfalls on Banks Peninsula. In this study

Zelandoperla sp. 1 were often collected from steep cascading streams reaches that are typical of the alternating riffle pool pattern that dominates the Peninsula. Although *Zelandoperla* sp. 1 can also occur amongst organic matter (mostly moss) they appear to be adapted to fast flowing riffle microhabitats. The preference of *C. peninsulae* to riffles was expected, as for the most part *Costachorema* are an alpine genus (Smith, 2002), suggesting they are well adapted to fast flowing steep stream conditions. *N. chiltoni* is the final regionally endemic species to show preference to faster flowing microhabitat environments. Other species belonging to Blephariceridae order live in mountainous streams like *Costachorema*, thus suggests that Blephariceridae are well adapted to faster flowing streams (Craig, 1969). The occurrence of *N. chiltoni* is somewhat surprising on the Peninsula, since its nearest conspecifics are found across the Canterbury Plains over 100 km away (Craig, 1969). However, the preference of *N. chiltoni* to fast flowing waters is consistent with previous studies, where they are suggested to occur when water velocities are fast enough (0.3 to 1.2 ms^{-1}) to keep boulders clear of thick algal growths, allowing grazing (Craig, 1969, Collier, 1992). The association of *Austrosimulium* spp. with faster flowing riffle environments, is consistent with other findings (e.g. Craig et al. (2012)). The occurrence of *Austrosimulium* spp. at lake outlets and in other fast flowing stream environments is thought to be because planktonic food material is more available (Craig et al., 2012).

Dobsonflies (*A. diversus*) were the only species to show preference to run microhabitats. However, the significant difference in the species occurrences across the microhabitats is probably driven by its rare occurrence in organic matter. Dobsonflies are characteristic of larger stony streams that have high bed movement and fast flows (Quinn and Hickey, 1990) and are known to occur in riffles (Devonport and Winterbourn, 1976). Furthermore, *A. diversus* require boulders and large cobble substrates along stream banks when moulting once they have emerged. This research supports their occurrence in faster flowing runs and riffles on the Peninsula, among course substrates. However, small *A. diversus* larvae can occur within the stream bed (Devonport and Winterbourn, 1976), which may explain why in this study they were collected from pools and organic matter, as the stream bed would have been disrupted when samples were collected.

Both *Zephlebia* spp. and *N. philpotti* have well known associations with slow flowing stream environments (Winterbourn et al., 2006). The association of *N. philpotti* with forested stream backwaters (Winterbourn et al., 2006), is consistent with their preference to pools on the Peninsula. Towns and Peters (1996) found that *Zephlebia* spp. were abundant of in slow flowing portions of lowland streams. This is consistent with the mayfly's macrohabitat preferences seen in this study.

The endemic *H. styx* and *Pycnocentria* sp. A were found to occur more frequently amongst organic matter. Both species rarely or never occurred in pools. Although *H. styx* were most frequently collected from organic matter, they were also occasionally found in riffle and run microhabitats, suggesting they may prefer faster flowing waters, where organic material is accumulating. It is possible that *Pycnocentria* sp. A is an undescribed species from the Peninsula or a variation of *Pycnocentria forcipata* (Winterbourn et al., 2006). However, the association of *Pycnocentria* sp. A with organic matter, is consistent with the association of *P. forcipate* with moss and wood (Winterbourn et al., 2006). Additionally, studies by Linklater and Winertbourn (1993) and Linklater (1995) on Banks Peninsula also found that *"P. forcipata"* occurred amongst leaf litter.

3.4.4 Conclusions

Banks Peninsula has particularly high stream invertebrate diversity compared to other ecoregions in New Zealand. Local diversity on the Peninsula is most likely hindered by the discontinuity of forest fragmentations and the frequency of anthropogenic land use. Native forest increases and becomes more continuous towards the southeast of the Peninsula, supporting higher stream diversity. Although local diversity may not be exceptionally high in forested streams, small forested streams at higher altitudes on the Peninsula contribute markedly to regional diversity. These forested streams also support several regionally endemic species, which are a unique part of invertebrate communities on Banks Peninsula. In certain streams regionally endemic taxa can account for over 20 percent of the diversity. Furthermore, several regionally endemic species seem to have developed highly specialised niches and favour the fast-flowing riffle complexes that dominate the Peninsula (*C. peninsulae, N. chiltoni,* and *Zelandoperla* sp. 1) or instream accumulations of organic matter (*H. styx*). This study demonstrates that the spatial distribution of stream invertebrates and invertebrate diversity on Banks Peninsula is influenced by large scale geographical patterns, stream shading, stream size, and elevation, and small-scale microhabitats preferences.

Chapter four: Discussion

4.1 Synthesis

The purpose of this thesis was to increase the knowledge and understanding of Banks Peninsula's regionally endemic stream invertebrates, which in turn could contribute to more informed management and conservation. Prior to this study little was known about the distribution of these species or their environmental and microhabitat preferences (Collier, 1992, Collier, 1993, Harding, 2003). Craig (1969) had conducted more intensive research on at least one of the Peninsula's regionally endemic stream invertebrates (*Neocurupira chiltoni*) and suggested it was widespread and abundant. However, it was unclear until my study if the Peninsula's other endemic species were truly rare or just not robustly sampled. Christchurch City Council have conducted several surveys in streams throughout the Peninsula. However, they have been unwilling to share that data (presumably due to agreements with landowners) and it is unpublished. Thus, the current threat classification of these species has been based on uncertain or inadequate data and has relied more on expert opinion (J. Harding, personal communication, 2019). My research has shown that seven regionally endemic species occur relatively frequently in the Peninsula's streams. However, I did not collect three of the Peninsula's regionally endemic species (*Edpercivalia banksiensis, Tiphobiosis childella,* and *T. hinewai*). Thus, suggesting they may be extremely rare or occupy very specialised microhabitats, which I did not sample.

Firstly, chapter two investigated the distribution of Banks Peninsula's regionally endemic stream invertebrates and explored what environmental variables were associated with their occurrences. This chapter then assessed whether three spatial conservation classifications could explain the distribution of these endemic species. The wide spatial distribution of the streams I surveyed enabled a robust assessment of the distribution of these endemics. By sampling 54 streams across the Peninsula I was able to confidently increase the known distributions of several species. However, due to land access limitations I was not able to survey several large stream systems (e.g. Purau, Te Kawa, Pawsons, and Waiake Streams), which have left some geographical gaps in the distributions. Despite this, the streams surveyed encompassed a wide range of river environments and ecosystems, as defined by the River Environment Classification (REC) and the Freshwater Ecosystems of New Zealand (FWENZ). My results suggest that the some of the current spatial classifications (e.g. FWENZ) used to guide conservation in New Zealand were not able to explain the distribution of stream invertebrates restricted to ranges < 100 000 ha. My research shows that when assessing stream invertebrate distributions across small regions, such as Banks Peninsula, the spatial resolution of FWENZ is too coarse to differentiate the habitat preferences of regionally endemic stream invertebrates. Therefore, the conservation management of stream invertebrates informed by spatial classifications should only be used as a general guide and always backed up with field observations.

My third chapter investigated the spatial diversity, community composition, and microhabitat preferences of stream invertebrates on Banks Peninsula. Although this section of my thesis was successful at determining the diversity of stream invertebrates across three spatial scales (regional, catchment, and locally), no clear drivers of catchment (beta) diversity were identified. In hindsight, catchment scale measurements (e.g. the percent cover of native vegetation per catchment or above a sampling site) would probably have been better measures to assess possible drivers of beta diversity. Instead the measurements used were coarse averages of native riparian vegetation cover. Additionally, catchment scale analysis, particularly of vegetation may have provided further insight into why certain endemic species were absent from forested stream reaches in lowland areas. Lastly, microhabitat assessment of the 18 stream invertebrates I selected for detailed analysis indicated several patterns that were consistent with other studies (e.g. *Deleatidium* and *Nannochorista philpotti*). Several of the regionally endemic species showed microhabitat preferences, especially towards faster flowing riffle environments (e.g. *Costachorema peninsulae, N. chiltoni,* and *Zelandoperla* sp. 1). This chapter highlights how locally endemic species accounted for ≥ 10 % of the diversity in nearly half of the streams I surveyed. Thus, combined with the strong microhabitat preferences of some regionally endemic taxa, suggest these endemics are an important part of the Peninsula's streams.

4.2 Current conservation efforts on Banks Peninsula

Many of the valleys and streams on the Peninsula include regenerating and remnant forest, which have some conservation protection. There are a number of localised trusts (e.g. the Rod Donald Banks Peninsula Trust and Maurice White Native Forest Trust), as well as QEII National Trust blocks, over 60 covenants developed by the Banks Peninsula Conservation Trust (M. Neal, personal communication, 2019), and 28 scenic reserves managed by the Department of Conservation (Department of Conservation, 2019). Hinewai Reserve, managed by the Maurice White Native Forest Trust is particularly important because two regionally endemic stream invertebrates (*T. childella,* and *T. hinewai*) are only known form this reserve (Ward, 1995). In my opinion the establishment of private "conservation" land on the Peninsula has been and will likely continue to be critical to protect a number of these regionally endemic species. Not only will this reduce forest fragmentation, but it may allow many of the stream invertebrates to recover from deforestation and expand their range through forested corridors along stream networks.

Although these pockets of forest provide a good foundation for native forest regeneration on the Peninsula. Some forested areas (formally protected or not) on the Peninsula have poor undergrowth development. Stock (cattle and sheep) and feral goats are known to destroy the undergrowth of native forests and cause localised soil erosion, which intern will be washed into nearby waterways (Cowan, 2016). I witnessed this in several streams. In unfenced or poorly fenced areas stock and feral goats have destroyed the undergrowth of regenerating kānuka and mixed forests on the Peninsula (Fig. 4.1). Soil erosion is a major issue on Banks Peninsula due to fine and poor structured loess soils (Yates et al., 2018), which are particularly prone to erosion on steep slopes where vegetation has been destroyed or is in poor condition. High levels of sedimentation in streams can reduce invertebrate diversity and result in a shift in stream fauna (Burdon et al., 2013). Additionally, stock in or adjacent to waterways can also increase stream nitrate levels and bacteria (e.g. Moller et al. (2008)). Feral goat control is frequently carried out on the Peninsula by the Department of Conservation (e.g. the 2018 Little Akaroa goat control operation (McTavish, 2018)), this combined with the increasing levels of funding available to fence forested areas of the Peninsula and community education suggests that forest health will improve.

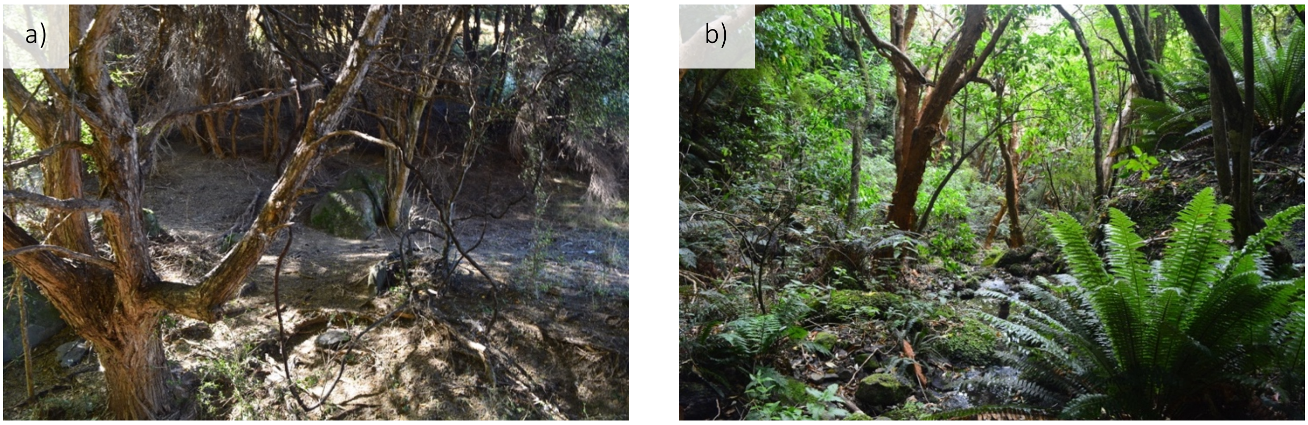


Figure 4.1: Comparison between an ungulate damaged section of riparian forest (a) and undamaged riparian vegetation (b).

Gorse (*Ulex europaeus*) and broom (*Cytisus scoparius*) are two widespread nitrogen fixing agricultural pest plants on the Peninsula. A study by Stewart (2011) found that streams with broom and gorse cover had the highest nitrate concentrations on the Peninsula. Furthermore, nitrate levels were found to be lowest in streams amongst regenerating forest, which corresponded with healthier stream invertebrate communities (Stewart, 2011). This research suggests that land use is an important influencer of stream conditions on the Peninsula and perhaps gorse and broom can influence stream conditions. In some of the Peninsula's catchments gorse and broom, which are good early succession species have been left to act as a nurse canopy for regenerating native seedlings (Wilson, 1994). This minimal interference method of letting native vegetation grow through weed species has been highly successful in some catchments on the Peninsula, such as Hinewai Reserve in the Narbey Stream Catchment (Wilson, 1994). Although control of gorse and broom is required to allow stock to graze. In marginal country where there are little benefits of grazing, headwaters covered with gorse and broom should perhaps be left (except for boundary control) and allowed to act as a nurse canopy for native seedlings, given the success of Hinewai Reserve. Additionally, the retirement, fencing, and planting of riparian zones in agricultural areas is also expected to improve stream invertebrate communities in lowland pastural areas. Because the majority of the lowland areas on the Peninsula are farmed, most of the larger streams and rivers

(3rd and 4th order) have poor shading and little native or mature riparian vegetation. My research indicated that larger streams have the highest levels of stream invertebrate diversity in the region and were important for several regionally endemic species. The conservation of these larger streams is particularly important given there is only a very few of these streams on the Peninsula. A local community project (Okuti River Project) has already recognised the biodiversity importance of the large Okuti River in the Wairewa Catchment and are actively restoring a kilometre-long lowland reach of the river (A. Evans, personal communications, 2019).

Climate change is likely to be a major threat facing the Banks Peninsula’s stream invertebrates in the years to come. Although many streams on the Peninsula are naturally ephemeral (e.g. around Lyttelton Harbour), as the temperatures warm I expect more streams will shrink or become ephemeral on the Peninsula, especially in areas where headwaters have little vegetation cover or catchments are small. During this study I was told by several landowners that some streams that once flowed year-round are now drying or becoming reduced to a trickle with isolated pools during the summer months (Fig. 4.2). Thus, suggests that climate change is already impacting streams on the Peninsula. However, another confounding factor is that many spring fed streams may have been altered (e.g. flow decrease) by the 2010/11 Canterbury Earthquake Sequence (Potter et al., 2015).

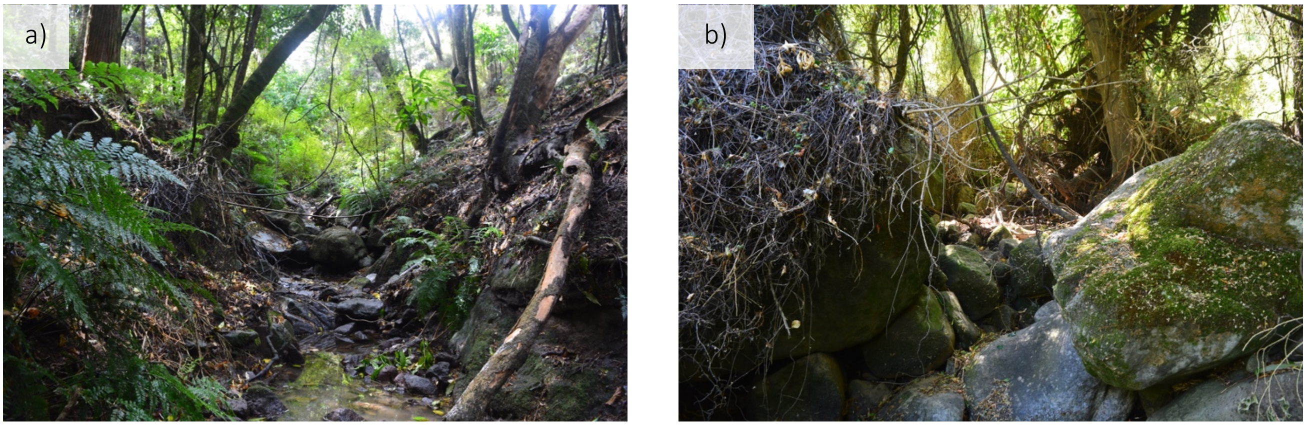


Figure 4.2: Ephemeral streams on Banks Peninsula. Where, a) shows a stream that reduces to a trickle in summer in established forest, and b) shows a dry stream with no forest in the catchment area above.

As climate change intensifies the protection of specific stream environments that show high levels of diversity (e.g. large streams) or streams that contribute specific diversity attributes (e.g. forested headwaters) will likely be critical for the survival of Banks Peninsula’s endemic and other stream invertebrates. I found that four regionally endemic species (*Nesameletus vulcanus,* and *Hydrobiosis styx, Zelandobius wardi,* and *Zelandoperla* sp. 1) were associated with forested streams at higher altitudes on the Peninsula. In particular the protection of these ecosystems will be essential for the conservation of *Zelandoperla* sp.1, which are not only restricted to forested headwaters but also show strong microhabitat preferences to fast flowing cascades and riffles that might shrink and disappear with climate change.

4.3 Conservation status review

Previous assessments of the conservation status of Banks Peninsula's regionally endemic stream invertebrates has been based on minimal scientific data. The Department of Conservation's New Zealand Threat Classification System (NZTCS) uses expert panels to assign conservation rankings to taxa based on available data and/or experience, particularly for data deficient taxa. Prior to this study several of the Peninsula's regionally endemic species were only known from a few catchments or descriptions in studies that are over 20 years old. Therefore, although some of the Peninsula's endemic stream invertebrates have now been assessed three times by Hitchmough et al. (2007), Grainger et al. (2014), and Grainger et al. (2018), the level of accuracy in these conservation rankings is unknown. I have extrapolated the information from my study and reviewed the conservation status of Banks Peninsula's regionally endemic stream invertebrates.

The NZTCS consists of 15 qualifier classes (Table 4.1) that are used to guide the classification's 14 different status categories (Fig. 4.3) (Townsend et al., 2008). Under the NZTCS taxa being assessed must met a status criterion and a general population trend to be assigned a conservation status. Therefore, information on either 1) taxa's population size, 2) the number of sub-populations and number mature individuals in the largest sub-population, or 3) the total occupancy area of a taxa needs to be known to assign a threat level. In addition to this the population trend of the taxon over the next 10 years or three generations (whichever is longer) should also be known. However, this information is particularly difficult to determine for freshwater invertebrates, making it hard to confidently assign conservation rankings. In a recent study, Pohe et al. (2019) recognised three main issues that reduce the confidence in which threat classifications can be assigned to stream invertebrates. Firstly, it is extremely difficult to measure the population size of stream invertebrates, and therefore for most species' population size is unknown. Secondly, stream invertebrates have complex life cycles, with some life history stages often more abundant in different seasons. Some mature aquatic insects live short terrestrial lives, while juvenile stages of stream invertebrates are much longer and are restricted to stream environments. Therefore, it is difficult to determine the number of mature individuals in a population. Furthermore, it is hard to define the occupancy area of stream invertebrates because they are restricted to narrow riparian corridors and stream systems. Thirdly, Pohe et al. (2019) suggested that there is currently no establish way to accurately measure the population trend of stream invertebrates.

Table 4.1: Qualifier descriptions abbreviated from the New Zealand Threat Classification System manual by Townsend et al. (2008). Qualifiers highlighted in bold are relevant to Banks Peninsula's regionally endemic stream invertebrates.

Qualifier	Description
Conservation Dependent (CD)	If current management stopped taxa are likely to move to a higher threat category
Data Poor (DP)	**Listing confidence low as there is only poor data available for taxa assessment**
Designated (De)	Taxon does not fit within the criteria provided
Extinct in the Wild (EW)	Taxon only in captivity or cultivation
Extreme Fluctuations (EF)	Taxa experience unnatural, or natural fluctuations on top of human induced decline, that increases the threat of extinction
Increasing (Inc)	Population increase of > 10 % ongoing or predicted over the next three generations or the next 10 years
Island Endemic (IE)	Taxa natural range is restricted to one island archipelago and does not naturally occur on the North, South, or Stewart Islands
One Location (OL)	**Only found at one location < 100 000 ha or 1000 km^2, which a single event could affect all individuals**
Partial Decline (PD)	Taxa undergoing decline across the majority of their natural range, but one or more populations are secure
Range Restricted (RR)	**Taxa confined to specific substrates, habitats, or geographic areas < 100 000 ha or 1000 km^2**
Recruitment Failure (RF)	Population appears stable, but age structure suggests catastrophic decline in the future is likely
Secure Overseas (SO)	Taxa is secure in its natural range outside of New Zealand
Sparse (Sp)	**Taxa typically occur in small and scattered populations**
Stable (St)	Population has remained stable (± 10 %) over its last three generations or the last 10 years
Threatened Overseas (TO)	Taxa is threatened in parts of its natural range out of New Zealand

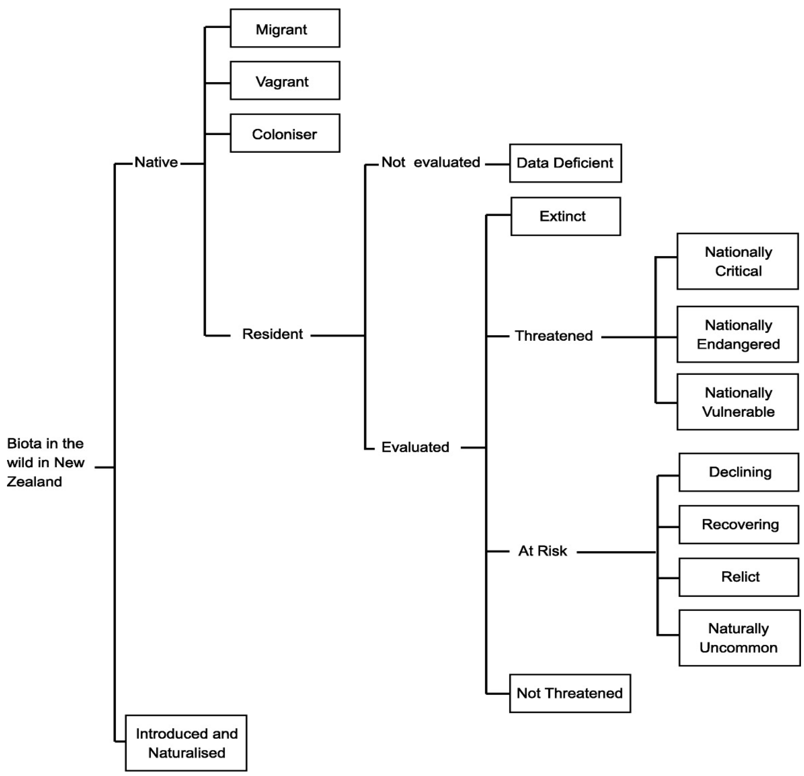


Figure 4.3: Structure of the New Zealand Threat Classification System from Townsend et al. (2008).

As these are significant limitations in our ability to use the NZTCS, I attempted a “rough” estimate method. I have taken a different approach to attempt to estimate the total the occupancy areas of Banks Peninsula’s stream invertebrates. I have used the River Environment Classification (REC) reach length of streams that I surveyed to estimate an occupancy area for seven of the Peninsula’s regionally endemic species. Each of my 54 streams surveyed is associated with a unique REC reach. Each of these REC reaches have consistent landscape characteristics and therefore, supposedly similar stream conditions. On average the REC reaches that encompassed my smaller survey reaches were 0.8 (± SE 0.01) km long. The occupancy area of each of regionally endemic species was estimated by summing the length of each river reach where I collected them and multiplying it by the average width (2 ± SE 0.2 m) of the streams surveyed on the Peninsula (Table 4.2). This method of calculating occupancy area, has several assumptions, meaning it could be an over estimation or an underestimation of the true occupancy areas of these taxa. Firstly, it assumes that the stream invertebrates occur throughout the whole REC river reach where they were collected. In this study taxa were only collected from a select few microhabitat environments over a small 10-15 m reach. Although the REC classes a similar or uniform environment as a single reach, it is possible that in some reaches endemics will not occur consistently along the whole reach length. Secondly, I have only calculated occupancy areas from reaches where I collected these invertebrates. These species may also occur in other REC reaches across the Peninsula and therefore these occupancy areas may be under estimations. However, this is an approximation based on evidence I have of the occurrence of these taxa.

I have also estimated the number of sub-populations of each regionally endemic species from my data (Table 4.2). Additionally, I have estimated the mean relative abundance of individuals per sub-population and the relative abundance of the largest sub-population for each taxon. In total I surveyed 41 different catchments, which were used to define the sup-populations of each species. These catchments ranged in size, and therefore some catchments had several survey streams. Catchments were chosen to define sub-populations as some of the endemic species are likely to have very small dispersal potentials, such as *Zelandoperla* sp. 1. These parameters were calculated to provide some insight into the occupancy area and sub-populations structures of the Peninsula’s endemic taxa so they could be compared with the criteria of the NZTCS.

Table 4.2: Estimated stream length, occupancy area, sub-population number, and sub-population abundances of seven regionally endemic stream invertebrates collected on Banks Peninsula, from a survey of 54 streams over the 2018/19 summer. Estimated stream length is based off the length of each River Environment Classification reach where taxa were collected. Occupancy areas were calculated by multiply stream length by 2 m (mean stream width). Sub-populations were defined as the number of catchments where each taxon was collected. The mean relative abundance was calculated by dividing the total number of individuals of a species collected in kick samples by the number of sub-populations. The largest sub-population abundance is defined as the highest number of individuals of a specie's collected from a catchment.

Species	Estimated stream length (km)	Approximate occupancy area (ha)	No. of sub-populations	Mean relative abundance per sub-population	Largest sub-population relative abundance
Costachorema peninsulae	15	3.0	19	2	4
Hydrobiosis styx	19	3.8	19	5	17
Neocurupira chiltoni	27	4.3	27	36	304
Nesameletus vulcanus	22	4.4	21	13	49
Orchymontia banksiana	29	5.7	27	15	62
Zelandobius wardi	18	3.7	18	10	36
Zelandoperla sp. 1	9	1.8	10	4	15

Based on my estimations all of the regionally endemic species (except *O. banksiana*) are restricted to < 5 ha (Table 4.2). With the exception of *Zelandoperla* sp. 1, all of the endemic species were collected from ≥ 18 different catchments on the Peninsula (Table 4.2). I found that the relative abundance of the largest sub-populations of these seven endemic taxa varied widely (Table 4.2). In my survey *C. peninsulae* were only collected in low abundances, and therefore the largest sub-population size consisted of only four individuals (Table 4.2). Two other invertebrates (*H. styx* and *Zelandoperla* sp. 1) also have notably low estimated sub-population abundances (Table 4.2). However, the remaining taxa (*N. chiltoni, O. banksiana, N. vulcanus,* and *Z. wardi*) all had large sub-population abundances (Table 4.2).

The conservation status of three regionally endemic species (*E. banksiensis, T. childella,* and *T. hinewai*) were not reassessed in this study, as I did not collect any individuals (Table 4.3). However, I am not sure if the range restricted (RR) qualifier is appropriate for *T. hinewai*, when it is limited to one location (OL) (Tables 4.1 and 4.3). I also suggest the data poor (DP) qualifier be added to *E. banksiensis,* because its absence in this study suggests that it is rare and potentially occupies unusual habitats (Table 4.3). I then reassessed the conservation status of the other seven regionally endemic stream invertebrates based on the estimates in Table 4.2. All seven species qualified as range restricted (Table 4.3). I considered three stream invertebrates (*C. peninsulae, H. styx,* and *Zelandoperla* sp. 1) to qualify as sparse (Sp). These species qualified as sparse because they occurred constantly low abundances (< 5 individuals collected per sub-population) or had small abundances (generally < 10 individuals per sub-population) and scatted populations that were discontinuous across the Peninsula (Table

4.2). I also suggest that the data poor qualifier is removed from *Zelandoperla* sp. 1, as my research has determined the species habitat preferences and its approximate distribution across the Peninsula.

I estimated the two most widespread species (*N. chiltoni* and *O. banksiana*) occupied areas of 4.3 and 5.5 ha, respectively. Both species have a good number of sub populations and high relative abundances compared to the other regionally endemic species (Table 4.2). My analysis suggests that the distribution of *N. chiltoni* has changed little over the last 50 years since the study of Craig (1969) and that the population has remained abundant and stable over this time. Therefore, *N. chiltoni* would be classed as 'Naturally Uncommon' because of its abundance and large population size, which appears to be stable across the species restricted range (Table 4.3). *O. banksiana* are also found in significantly lower abundances than *N. chiltoni.* Therefore, I have placed *O. banksiana* under the 'Nationally Vulnerable' criteria of B(3) as I considered the population to be moderate, but stable (Table 4.3).

The two caddisfly species (*C. peninsulae* and *H. styx*) have similar occupancy areas, number of sub-populations, and mean relative abundances (Table 4.2). Because both species were collected from 19 catchments, I suggest they no longer fit the B(2) 'Nationally Vulnerable' criteria of a moderate stable population consisting of ≤ 15 sup-populations. Therefore, I recommend both species are placed as 'Nationally Vulnerable' under the category A(3), which suggests they are a small unnatural increasing population, that are restricted to ≤ 10 ha (Table 4.3). The population of these species is likely to increase on the Peninsula over the next 10 years, if the current trend of forest regeneration continues.

I also propose the mayfly, *N. vulcanus* is reclassified as 'Nationally Vulnerable' under the criteria of B(3), which suggests the mayfly has a moderate stable population due to unnatural causes and has a total occupancy area of ≤ 10 ha (Table 4.3). *N. vulcanus* was assigned this conservation status as it has 22 sub-populations, which often had high relative abundances compared to the other endemic species (Table 4.2). The stonefly *Z. wardi* has a similar distribution (but more restricted) and a similar number of sub-populations compared with *N. vulcanus* (Table 4.2). Therefore, I recommend *Z. wardi* is also classed as 'Nationally Vulnerable' under the criteria B(3) (Table 4.3).

Lastly, *Zelandoperla* sp. 1 was collected from 10 sub-populations at low abundances on the Peninsula (Table 4.2). It is unlikely that this stonefly disperses between catchments as the species is flightless and therefore, have very limited dispersal potential. Based on the stream reaches where *Zelandoperla* sp. 1 were collected, I suggest the species may be limited to approximately 9 kilometres of stream or just under 2 ha. Therefore, I propose *Zelandoperla* sp. 1 is reclassified as 'Nationally Endangered' under the criteria B(3). Under this status and criteria

Zelandoperla sp. 1 is considered to consist of a small stable population due to unnatural reasons, which occupies are area ≤ 10 ha (Table 4.3).

Table 4.3: Current and revised conservation status of Banks Peninsula's regionally endemic stream invertebrates. Conservation status assessments were based on my opinion, following the guidelines of the New Zealand Threat Classification System by Townsend et al. (2008). The current recommended conservation status of *Neocurupira chiltoni* listed below is based off the work of Andrew et al. (2012).

Name & authority	Conservation Status	Criteria	Qualifiers	Status change
Costachorema peninsulae	Current status: Nationally Vulnerable	B(2)	RR	
(Ward, 1995)	Reviewed status: Nationally Vulnerable	A(3)	RR, Sp	No change
Edpercivalia banksiensis	Current status: Nationally Endangered	B(3)	RR, Sp	
(McFarlane, 1939)	-	-	DP, RR, Sp	Not reassessed
Hydrobiosis styx	Current status: Nationally Vulnerable	B(2)	RR, Sp	
(McFarlane, 1951)	Reviewed status: Nationally Vulnerable	A(3)	RR, Sp	No change
Neocurupira chiltoni	Current status: Naturally Uncommon	-	RR	
(Campbell, 1921)	Reviewed status: Naturally Uncommon	-	RR	No change
Nesameletus vulcanus	Current status: Nationally Endangered	B(3)	-	
(Hitchings and Staniczek, 2003)	Reviewed status: **Nationally Vulnerable**	**B(3)**	**RR**	**Better**
Orchymontia banksiana	Current status: Nationally Vulnerable	C(3)	RR	
(Ordish, 1984)	Reviewed status: Nationally Vulnerable	B(3)	RR	No change
Tiphobiosis childella	Current status: Nationally Critical	A(3)	DP, OL	
(Ward, 1995)	-	-	-	Not reassessed
Tiphobiosis hinewai	Current status: Nationally Critical	A(3)	DP, OL, RR	
(Ward, 1995)	-	-	DP, OL	Not reassessed
Zelandobius wardi	Current status: Nationally Endangered	B(3)	RR	
(McLellan, 1993)	Reviewed status: **Nationally Vulnerable**	**B(3)**	**RR**	**Better**
***Zelandoperla* sp. 1**	Current status: Nationally Vulnerable	B(3)	DP	
(BJF00160; Banks Peninsula)	Reviewed status: **Nationally Endangered**	**B(3)**	**RR, Sp**	**Worse**

Based on these estimates, the conservation status of only one species might be considered worse. The status of four species has remained the same as the assessments of Andrew et al. (2012) and Grainger et al. (2018). Two species are considered to be less threatened than their listings by Grainger et al. (2018). However, only one species (*N. chiltoni*) is classified as 'Naturally Uncommon', which the best possible conservation status the Peninsula's endemic species can hold, given their naturally restricted distributions.

4.4 Study limitations

I only sampled benthic stream invertebrates in this study, and this may be the most significant limitation of my study. If I had sampled aquatic adult insects, I would have been able to more confidently identify some of the stream invertebrates I found. Identification was particularly difficult for invertebrates that are rarely identified to a species level from nymphs, such as the *Zelandobius* genera. Adult insects would have also allowed another investigative level to assess the regionally endemic stream taxa. Another shortcoming of this study was the microhabitats I sampled. For example, species such as *E. banksiensis* possibly occupy seepages, meaning these habitats may be particularly important habitat for some of the regionally endemic species. If I was to carry out this survey again, I would add an additional survey targeting seepage environments. This survey should include both adult and nymph sampling to maximise collection potential.

I would also change how I sampled riparian vegetation, especially native vegetation on the Peninsula. I visually estimated the proportion of different vegetation types (e.g. exotic and regenerating native forest). However, I think a more robust assessment of vegetation, including approximate vegetation cover upstream of sampling sites would have helped reinforced how much native vegetation regionally endemic species require. This could be done using spatial data and aerial imagery. Lastly, in hindsight I should have also collected water samples for a complete chemical analysis of elements in addition to the spot water chemistry information I collected. Water samples would have been able to complement my spot measurements and may have provided further insight into the characteristics of stream environments favoured by particular endemic species or invertebrate communities.

4.5 Areas for further research

During this study I collected two taxa (*Pycnocentria* sp. A and *Austridotea* sp. A) that I was unable to confidently identify to species level (Fig. 4.4). *Pycnocentria* sp. A when examined keyed out to be *Pycnocentria forcipata* based on Winterbourn et al. (2006). However, Winterbourn et al. (2006) suggests that *P. forcipata* from Banks Peninsula may be an undescribed *Pycnocentria* species, which have been previously recorded as *P. forcipata* by Linklater and Winertbourn (1993) and Linklater (1995). Therefore, *Pycnocentria* sp. A is either a morphological variation or an undescribed species. I did not collect adults, nor was I able to test them genetically so confident identification is problematic of this taxon. The second species *Austridotea* sp. A does not match the morphological description of other isopods in the *Austridotea* genus found on Banks Peninsula. *Austridotea* sp. A lacked the distinctive pointed pleotelson of *A. annectens* (which occurs on Banks Peninsula), instead the pleotelson was rounded (Fig. 4.4e). Secondly, *Austridotea* sp. A did not appear to have segmented maxilliped palp like *A. annectens* and *A. benhami* (Fig. 4.4f) (Johns and Fenwick, 2007). Therefore, it is possible that *Austridotea* sp. A may be *A. lacustris.* However, the geographic distribution *A. lacustris* is supposedly limited to the southern South Island, and Stewart, Campbell, and Pitt Islands (Johns and Fenwick, 2007). Thus, meaning it is highly unlikely to occur in the warmer climate of Banks Peninsula. Therefore, as a precaution I have recorded the taxa as *Austridotea* sp. A, because it does not fit the morphological or known geographic description of any *Austridotea* species. Clarification of these two taxa needs to be refined with further morphological comparisons to similar species from other parts of the country and/or genetic analysis.

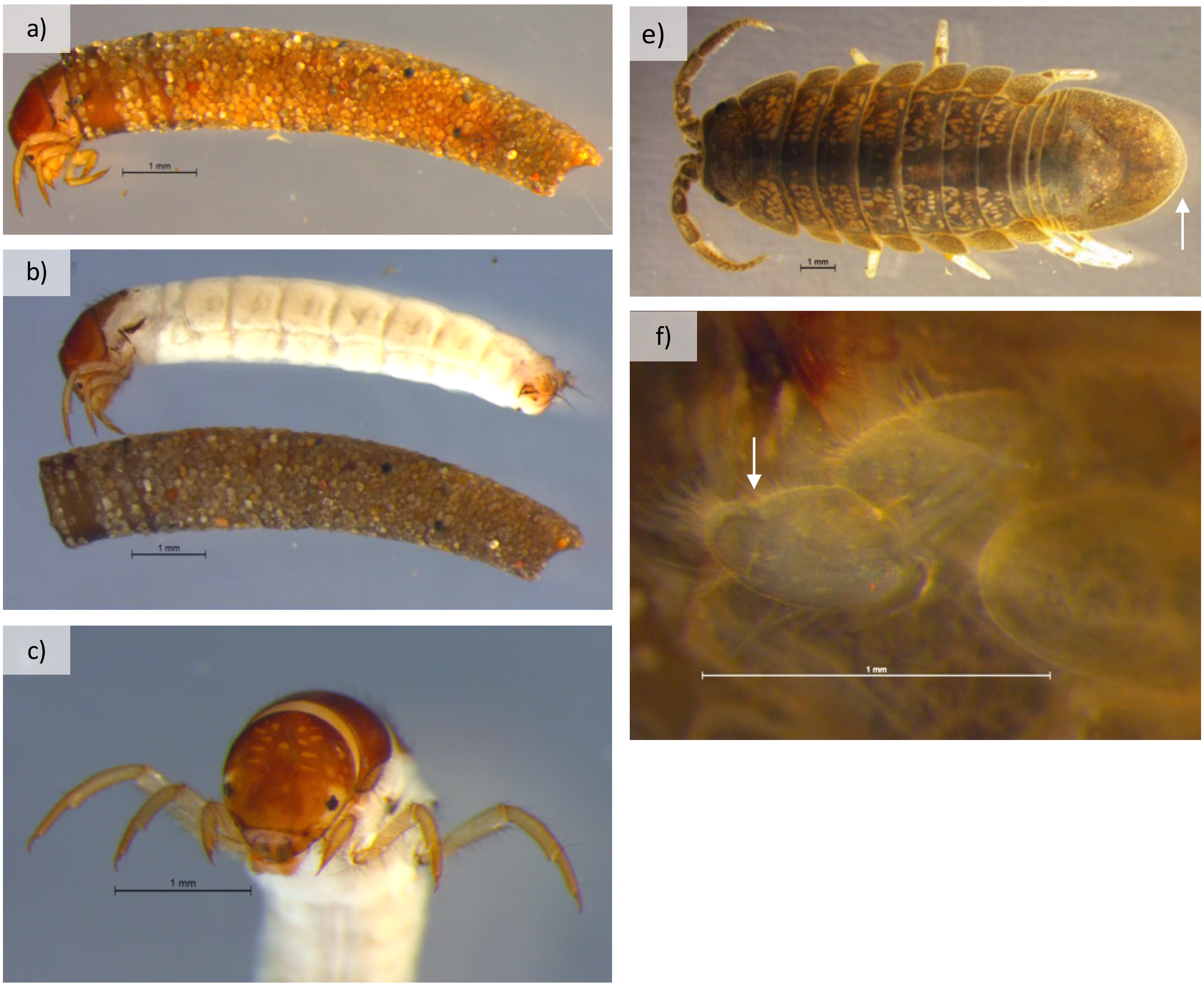


Figure 4.4: Images of two unidentified taxa, *Pycnocentria* sp. A (a-c) and *Austridotea* sp. A (e and f) collected from Banks Peninsula over the 2018/19 summer. Image f. shows the unsegmented maxilliped palp of *Austridotea* sp. A. Scale bar = 1 mm.

In this benthic study invertebrates were only collected from streams. If adult trapping was carried out as well, I would have expected a larger diversity of insects to have been collected. Adult trapping would have also increased the probability of capturing the endemic species that were not collected in the kick net method used in this study or other sparsely occurring invertebrates. I did not collect the larvae of three threatened regionally endemic species (*T. childella, T. hinewai,* and *E. banksiensis*). It is likely these species were missed because they may show strong preferences to stream seepages (B. Smith, personal communications, 2019). If adult sampling was carried out these data poor endemics and other sparse or rare species may have been collected. Future, invertebrate work investigating biodiversity and regionally endemic stream invertebrates on the Peninsula should include both nymph and adult invertebrate collection to increase to probability of collecting data poor taxa and improve identification confidence.

4.6 Conclusion

My thesis has indicated that Banks Peninsula's regionally endemic stream invertebrates are more widely distributed than expected despite of the extent of the region's historic deforestation. However, the sub-populations of these endemic stream invertebrates still bear the signs of the Peninsula's deforestation. These regionally endemic invertebrates were found in scattered, clustered, or isolated sub-populations across the Peninsula. If forest headwaters are protected and native riparian is vegetation safeguarded, this will ensure in time continuous stream reaches are protected. Thus, allowing regionally endemic species and other invertebrates of Banks Peninsula's diverse stream fauna to be conserved.

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APPENDICES

Appendix 1: Identification of *Zelandoperla* sp. 1 (BJF00160: Banks Peninsula)

Recently a regionally endemic stonefly from the *Zelandoperla* genus has been recognised from Banks Peninsula (McCulloch et al. (2009), McCulloch et al. (2016), B. Foster, personal communications, 2019). In this study this undescribed *Zelandoperla* taxa was identified to a genus level following the key of Winterbourn et al. (2006). However, to confirm this species was the undescribed stonefly recognised by McCulloch et al. (2009) from Banks Peninsula, specimens were sent to the University of Otago for genetic analysis.

Methods: Four representative individuals of the *Zelandoperla* collected from my survey of Banks Peninsula from the 2018/19 summer were selected for genetic analysis. These individuals were sequenced for a 644-bp portion of the mitochondrial cytochrome c oxidase subunit I (COI) region (B. Foster, personal communication, 2019). The methods of DNA extraction, amplification, and sequencing followed the methods of McCulloch et al. (2016). Sequences acquired from these four individuals were then compared with existing sequences on GenBank using a basic local alignment search tool (BLAST) (B. Foster, personal communication, 2019). See http://www.ncbi.nlm.nih.gov/BLAST for more detail.

Results: The BLAST sequences of these four *Zelandoperla* individuals showed the most similarity to clade 5 of the *Zelandoperla fenestrata* species group recognised by McCulloch et al. (2009) from Banks Peninsula. Clade 5 *Zelandoperla* are the same species as the undescribed stonefly, *Zelandoperla* sp. 1 (BJF00160: Banks Peninsula) assessed in the most recent Conservation status of New Zealand freshwater invertebrates by Grainger et al. (2018).

Based on the results of this genetic analysis, the previous work of McCulloch et al. (2009), McCulloch et al. (2016), Veale et al. (2018), and personal communications with B. Foster, this undescribed *Zelandoperla* species is considered to be regionally endemic species of Banks Peninsula. *Zelandoperla* sp. 1 (BJF00160: Banks Peninsula) will be formally described in 2019/2020 (B. Foster, personal communication, 2019).

Appendix 2: Images of regionally endemic stream invertebrates from Banks Peninsula

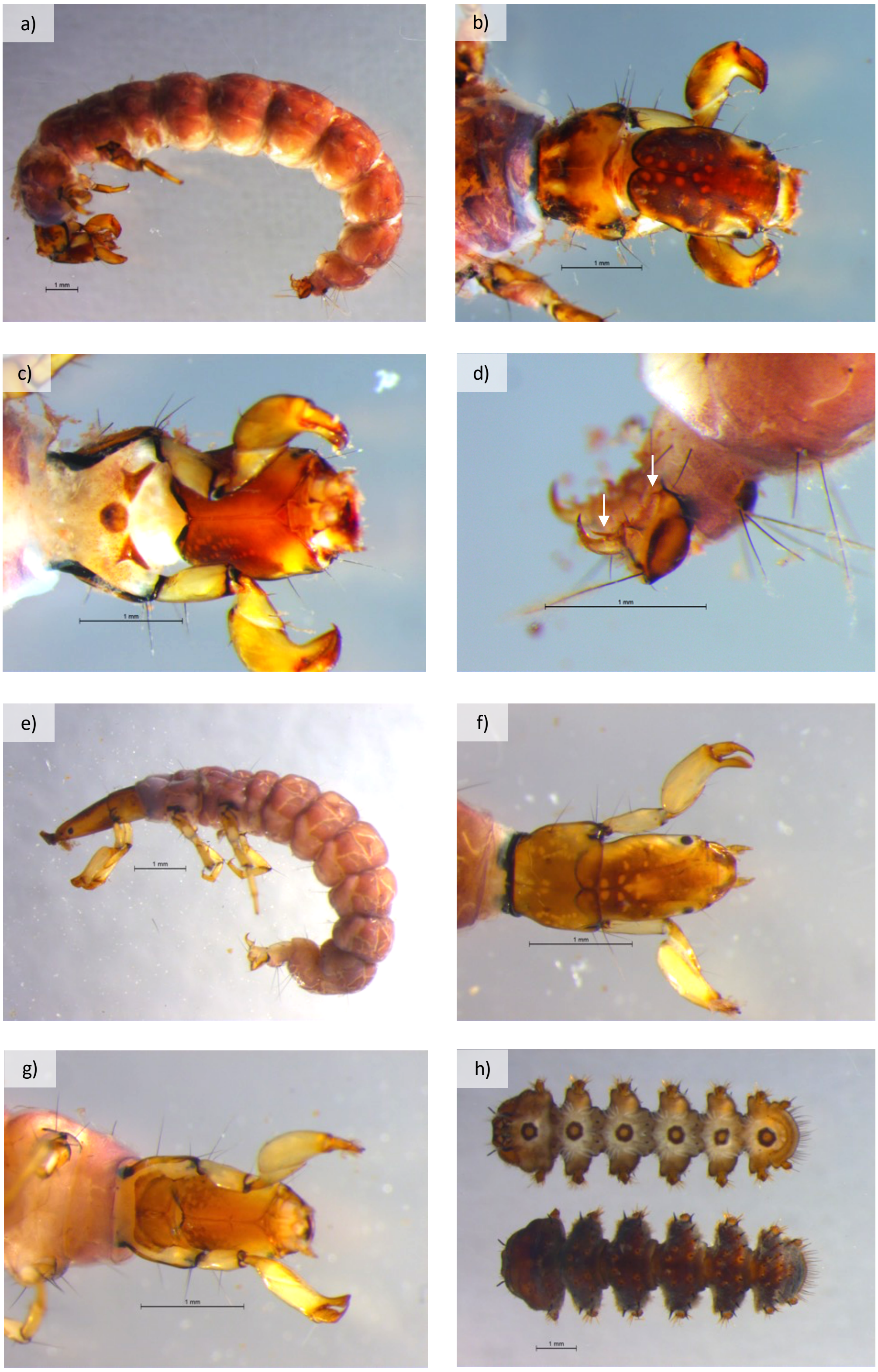


Figure A1: Images of the seven regionally endemic stream invertebrates collected over the summer of 2018/19 on Banks Peninsula. Showing the larvae (a), head and pronota (b), postrenal plate (c) and basal proleg spines (d) of *Costachorema peninsulae*. The larvae (e), head and pronota (f), and postrenal plate (g), of *Hydrobiosis styx* and the larvae of *Neocurupira chiltoni* (h). Scale = 1 mm.

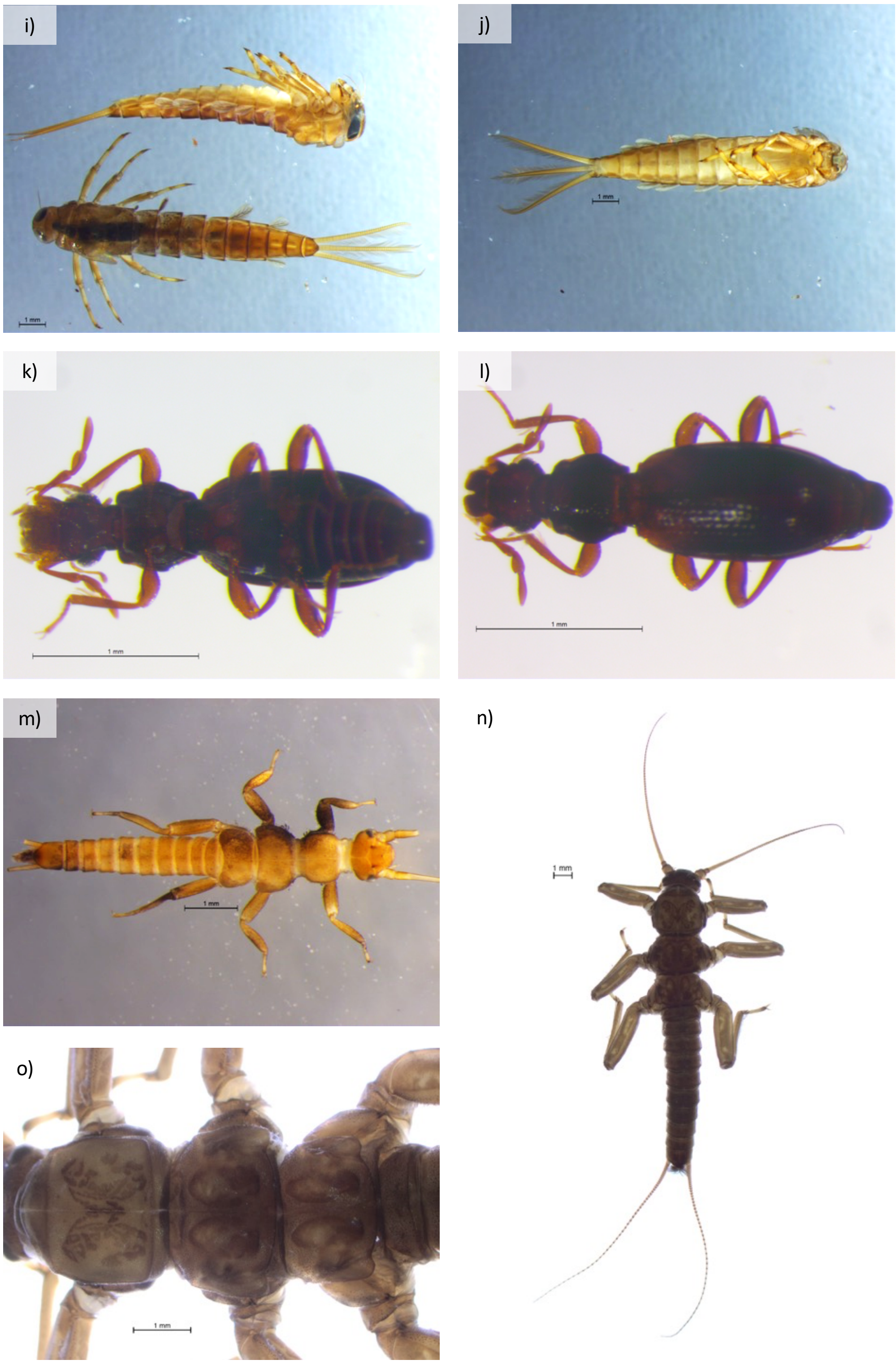


Figure A1 continued: Images showing the nymph of *Nesameletus vulcanus* (j and i), *Orchymontia banksiana* adult (k and l), *Zelandobius wardi* nymph (m), and a *Zelandoperla* sp. 1 (BJF00160: Banks Peninsula) nymph (n and o). Images of *Zelandoperla* sp. 1 were supplied by Brodie Foster. Scale = 1 mm.

Appendix 3: Spearman's correlation values for physico-chemical data

Table A1: Spearman's rank correlations between physico-chemical variables. Correlations in bold are statically significant, where p < 0.05 = *, p < 0.01 = **, and p < 0.001 = ***.

	Altitude	Stream shading	Native riparian cover	Substrate Index	Channel stability	Stream width	pH	Conductivity	Temperature	Dissolved oxygen	Turbidity	Flow
Stream shading (%)	**0.64*** **											
Native riparian cover (%)	**0.77*** **	**0.68*** **										
Substrate Index	**0.38** **	**0.33* **	**0.37** **									
Channel stability	**-0.51*** **	**-0.32* **	**-0.52*** **	**-0.46*** **								
Stream width (m)	**-0.42*** **	**-0.39** **	**-0.36** **	-0.19	0.14							
pH	**-0.43** **	**-0.51*** **	**-0.44*** **	**-0.53*** **	**0.29* **	**0.36** **						
Conductivity (µS/cm at 25°C)	**-0.33* **	**-0.34* **	**-0.30* **	**-0.34* **	**0.35** **	-0.20	0.26					
Temperature (°C)	**-0.56*** **	**-0.38** **	**-0.49*** **	**-0.47*** **	**0.31* **	0.21	**0.31* **	0.23				
Dissolved oxygen (mgL^{-1})	0.24	0.03	0.14	0.17	-0.20	0.22	0.20	**-0.31* **	**-0.56*** **			
Turbidity (NTU)	0.01	0.04	-0.02	**-0.29* **	0.19	0.12	0.14	0.25	**0.29* **	-0.09		
Stream flow (ms^{-1})	-0.24	-0.23	-0.22	-0.03	-0.08	**0.60*** **	0.20	**-0.34* **	0.25	0.20	0.12	
Stream depth (m)	-0.15	-0.08	-0.19	0.08	-0.21	**0.53*** **	0.13	**-0.31* **	0.18	**0.27* **	0.06	**0.55*** **

Appendix 4: Map of survey streams and codes

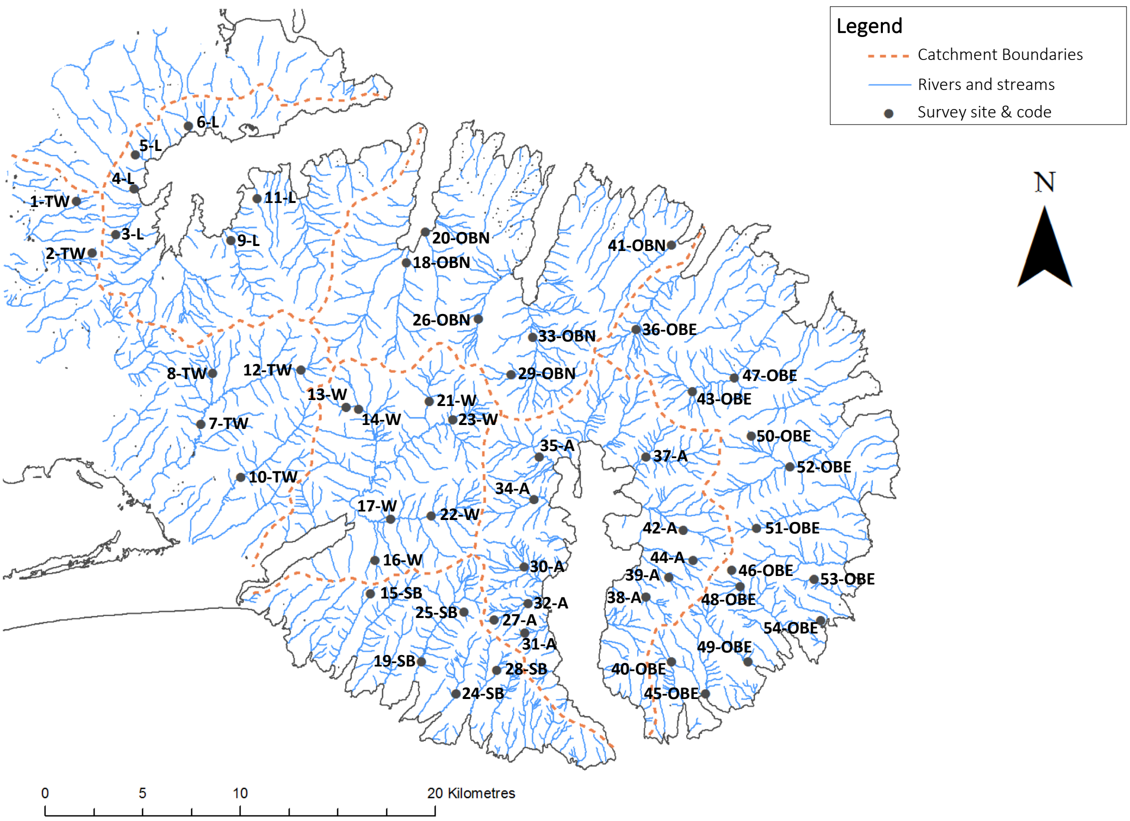


Figure A2: Map of Banks Peninsula showing the 54 streams surveyed in this study and their respective stream codes. Stream codes are ordered by pseudo-catchment areas, from west to east these are: TW = Te Waihora, L = Lyttelton, W = Wairewa, OBN = Northern Outer Bays, SB = Southern Bays, A = Akaroa, and OBE = Eastern Outer Bays.

Appendix 5: Freshwater Ecosystems of New Zealand macroinvertebrate distributions by Leathwick et al. (2009)

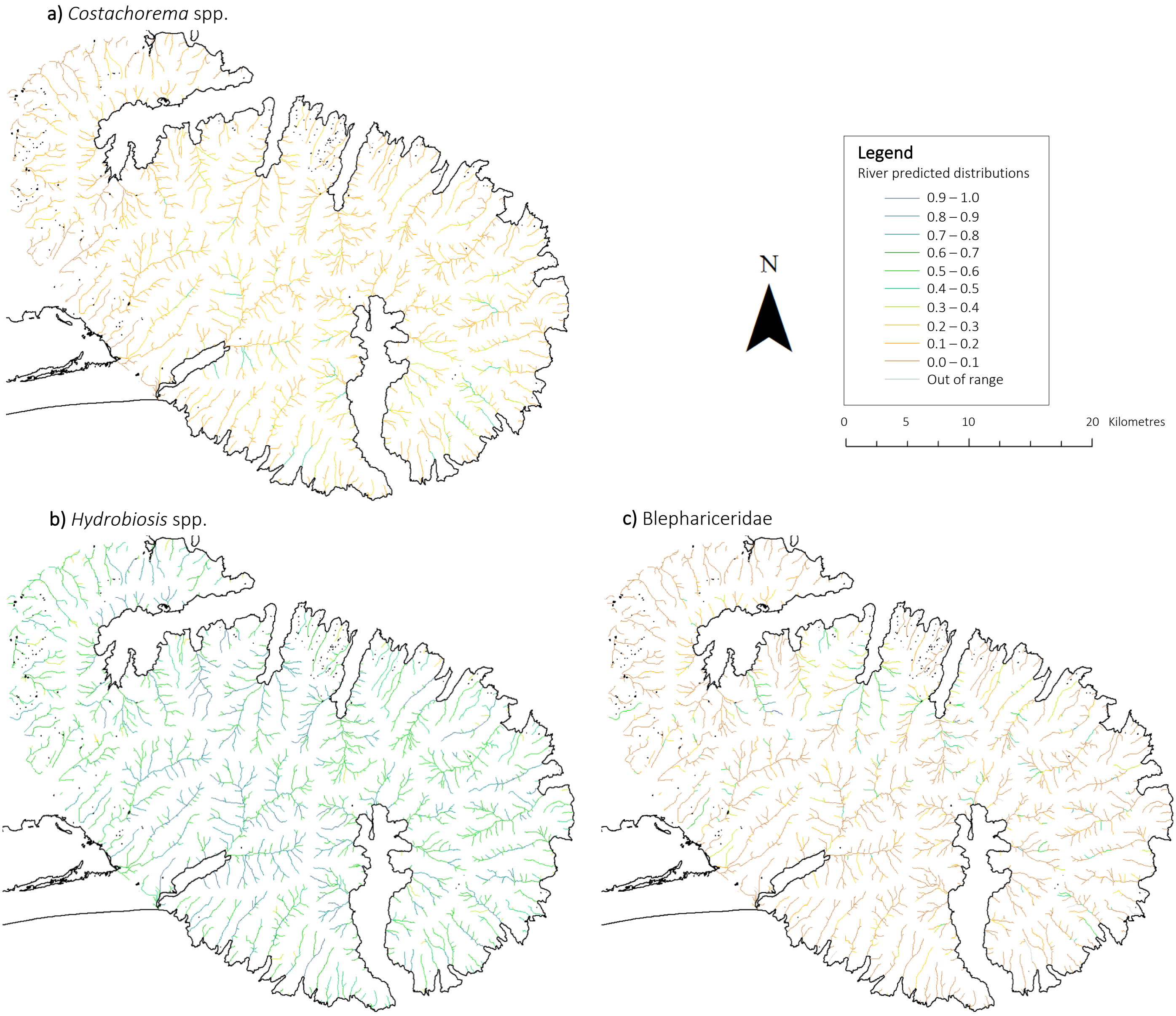
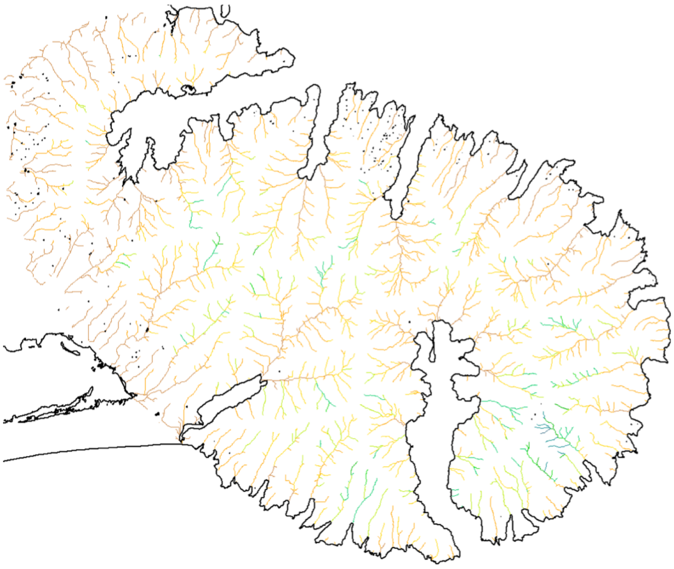
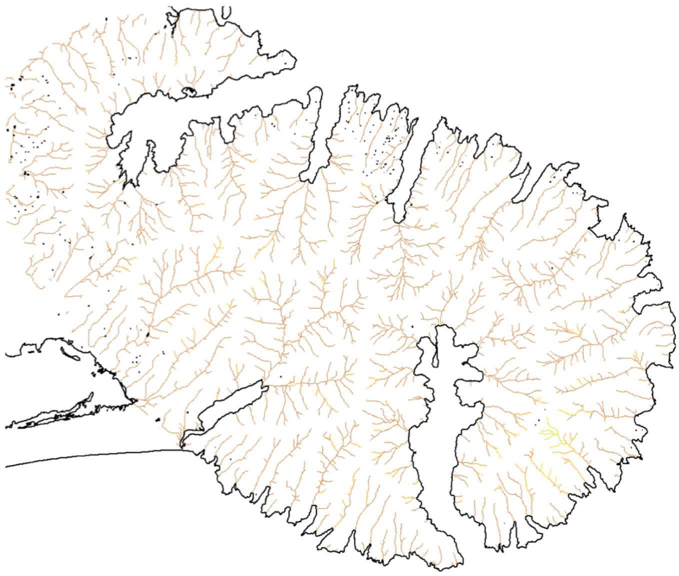


Figure A3: Predicted distributions by Leathwick et al. (2009) of the genera or family of seven regionally endemic stream invertebrates from Banks Peninsula, based off the Freshwater Ecosystems of New Zealand. Maps produced from the FWENZ data base.

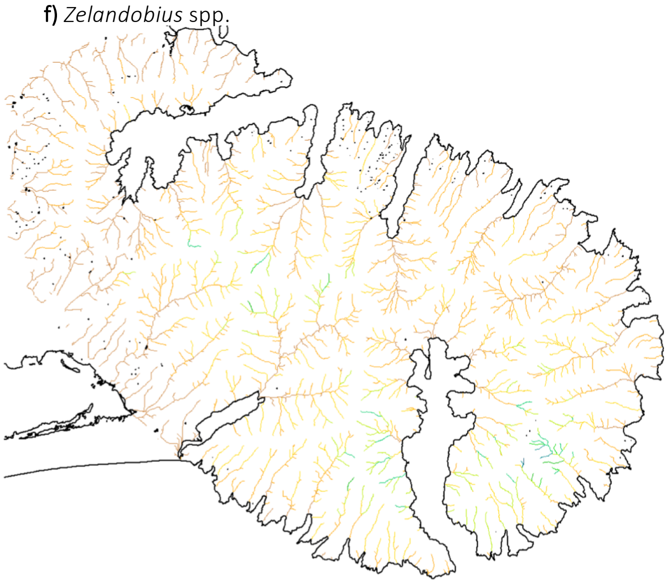
d) *Nesameletus* spp.



e) Hydraenidae



f) *Zelandobius* spp.



g) *Zelandoperla* spp.

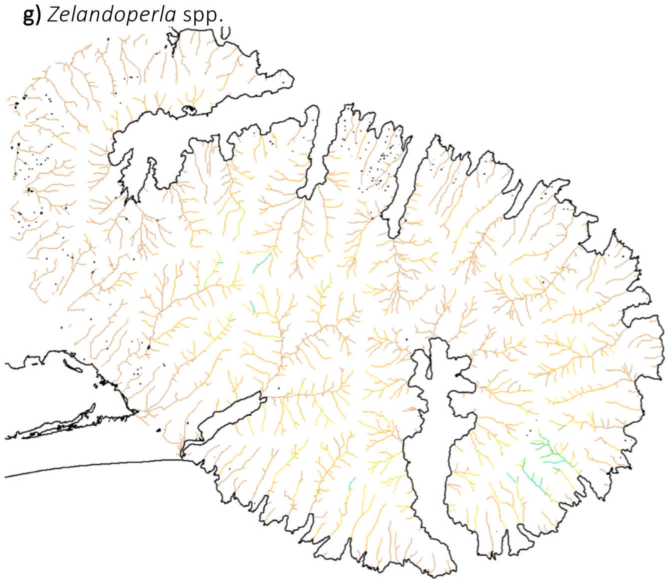


Figure A3 continued

Appendix 6: Stream locations and physico-chemical data

Table A2: Stream locations and physico-chemical data

Stream code	Stream order	Northing	Easting	Altitude (m a.s.l.)	Shade cover (%)	Substrate Index	pH	Conductivity (µS/cm at 25°C)	Temperature (°C)	Dissolved oxygen (ppm)	Turbidity (NTU)	Stream width (m)	Native riparian vegetation cover (%)	Stream Stability Score	Average depth (m)	Average velocity (m/s)
1-TW	1	5168106	1568393	219	90	6.3	6.8	248	11.2	8.4	2.2	0.05	93	69	0.09	0.01
2-TW	1	5165465	1569227	353	91	6.0	7.0	161	9.7	10.9	3.7	0.41	97	57	0.08	0.10
3-L	2	5166411	1570405	182	94	5.1	7.8	191	13.3	10.1	4.8	0.90	100	59	0.10	0.19
4-L	1	5168741	1571356	24	81	4.7	7.4	167	13.9	9.8	4.7	0.48	0	66	0.09	0.13
5-L	1	5170498	1571435	95	98	6.1	6.3	119	13.3	6.5	1.4	0.50	86	64	0.19	0.01
6-L	2	5171948	1574126	34	82	5.4	6.9	140	13.9	8.2	2.9	0.12	58	74	0.11	0.03
7-TW	4	5156657	1574784	19	48	5.1	7.7	105	12.8	12.2	1.5	5.40	81	93	0.26	0.48
8-TW	3	5159282	1575369	120	98	6.1	7.4	145	11.8	10.8	2.2	1.25	90	61	0.20	0.30
9-L	3	5166088	1576326	23	84	5.6	7.6	157	14.7	9.8	1.8	2.40	0	77	0.17	0.16
10-TW	3	5153944	1576818	50	52	5.7	7.6	126	15.0	10.4	3.0	3.60	40	66	0.22	0.54
11-L	1	5168252	1577663	147	67	6.5	7.0	127	15.0	9.3	1.5	0.85	100	51	0.09	0.19
12-TW	2	5159445	1579908	243	95	6.2	6.1	102	13.8	10.2	2.8	2.00	93	49	0.36	0.31
13-W	2	5157539	1582216	296	90	5.6	7.0	99	11.5	10.8	4.2	2.20	98	52	0.24	0.49
14-W	3	5157447	1582875	170	94	5.4	7.2	108	12.5	10.7	3.5	3.05	95	81	0.12	0.40
15-SB	1	5147980	1583452	445	99	6.3	6.1	137	9.0	10.8	5.5	0.70	100	73	0.05	0.01
16-W	2	5149696	1583715	158	72	4.9	7.1	156	15.0	9.9	8.8	2.00	85	101	0.11	0.09
17-W	3	5151815	1584509	34	60	5.9	6.7	123	12.5	9.8	2.7	4.81	5	67	0.22	0.48
18-OBN	3	5164967	1585316	16	10	5.9	7.4	163	12.1	10.9	4.3	3.50	0	55	0.15	0.45
19-SB	3	5144500	1586077	14	15	5.8	7.5	125	14.2	10.7	2.1	5.30	2	67	0.27	0.30
20-OBN	2	5166526	1586273	10	33	5.3	7.4	192	14.5	9.9	1.9	1.00	80	65	0.17	0.27
21-W	2	5157838	1586472	175	95	4.5	7.1	162	15.7	9.0	10.8	1.30	79	105	0.10	0.17
22-W	3	5151987	1586582	101	84	5.7	7.3	104	13.2	10.6	5.2	7.60	95	54	0.27	0.51
23-W	3	5156906	1587679	151	84	5.5	7.2	137	15.3	10.0	5.7	1.50	94	54	0.31	0.14
24-SB	3	5142840	1587863	83	89	5.9	7.0	84	14.1	10.2	3.6	2.55	83	74	0.20	0.44
25-SB	2	5147041	1588261	348	88	7.3	6.8	120	10.2	10.9	2.7	0.42	90	54	0.20	0.38
26-OBN	3	5162052	1588991	184	46	5.9	7.6	128	13.6	10.2	4.3	2.00	26	47	0.23	0.53
27-A	1	5146623	1589812	439	88	6.2	6.8	92	9.7	10.9	1.8	0.20	98	49	0.12	0.13
28-SB	2	5144058	1589937	312	96	6.7	7.0	123	13.2	10.0	3.4	0.27	98	57	0.20	0.17
29-OBN	2	5159233	1590694	229	91	5.4	7.6	70	11.6	10.7	6.3	2.00	93	69	0.18	0.36
30-A	3	5149350	1591349	60	90	5.7	6.9	132	15.3	9.9	2.9	0.80	95	55	0.23	0.53
31-A	2	5145957	1591390	184	70	5.5	7.9	143	11.4	10.7	1.4	0.80	87	61	0.17	0.21
32-A	3	5147484	1591542	83	96	5.8	6.9	120	15.6	9.8	5.1	1.50	90	61	0.24	0.50
33-OBN	3	5161136	1591787	38	68	5.3	7.5	164	14.4	10.2	10.6	3.90	65	66	0.35	0.39
34-A	3	5152805	1591858	31	46	5.1	7.2	143	15.7	9.9	2.7	2.00	0	70	0.19	0.49
35-A	3	5154991	1592126	30	47	5.6	7.2	173	19.4	9.0	8.1	3.20	87	75	0.11	0.53
36-OBE	3	5161547	1597071	167	91	5.7	6.8	143	13.0	10.3	4.9	1.83	91	58	0.25	0.36
37-A	3	5154989	1597579	27	25	5.2	7.7	206	21.1	8.6	4.0	3.20	3	76	0.19	0.24
38-A	3	5147800	1597600	151	88	5.3	7.3	131	14.0	10.4	4.2	2.10	70	67	0.36	0.23
39-A	2	5148802	1598772	146	85	6.1	7.3	121	14.9	10.2	3.5	2.30	72	55	0.25	0.45
40-OBE	2	5144478	1598900	325	89	5.8	6.7	104	10.6	10.7	0.8	2.50	95	50	0.15	0.18
41-OBN	2	5165845	1598902	14	53	5.5	7.8	60	15.3	10.6	2.8	1.40	0	83	0.14	0.36
42-A	2	5151237	1599499	124	78	5.6	7.5	121	15.6	12.1	7.3	2.87	62	51	0.34	0.45
43-OBE	2	5158334	1599965	136	63	5.9	7.3	185	12.5	10.6	5.0	1.10	90	79	0.17	0.22
44-A	2	5149701	1599996	223	94	5.2	7.3	115	14.4	10.1	2.5	1.90	93	54	0.18	0.55
45-OBE	2	5142852	1600658	2	74	5.7	7.1	135	13.4	10.6	1.6	2.50	4	72	0.16	0.22
46-OBE	1	5149193	1601993	448	96	5.8	7.0	89	9.8	11.2	2.2	1.47	99	52	0.14	0.31
47-OBE	4	5159047	1602123	24	1	5.7	7.7	157	13.0	11.0	2.5	4.10	3	78	0.23	0.39
48-OBE	3	5148357	1602426	202	92	6.0	7.5	107	11.0	11.3	2.1	4.40	99	47	0.33	0.30
49-OBE	3	5144484	1602827	42	88	5.8	6.9	139	13.0	10.8	1.5	1.50	45	60	0.31	0.41
50-OBE	1	5156054	1602976	346	86	5.6	6.2	127	12.1	9.8	1.4	0.86	98	51	0.08	0.06
51-OBE	2	5151333	1603256	326	96	6.4	6.8	102	10.3	11.0	2.7	1.80	97	54	0.24	0.42
52-OBE	3	5154488	1604974	52	64	5.7	7.0	120	13.9	10.3	3.3	3.40	35	79	0.31	0.70
53-OBE	2	5148729	1606217	162	0	5.2	7.6	174	14.2	11.0	2.8	1.20	3	85	0.20	0.26
54-OBE	1	5146603	1606554	40	88	5.2	7.3	301	12.9	10.8	12.3	1.63	89	64	0.17	0.15

Appendix 7: Stream Ecological Districts, River Environments, and Freshwater Ecosystems

Table A3: Ecological Districts, River Environment Classifications, and Freshwater Ecosystems of New Zealand assigned to each stream reach surveyed in this study.

Stream code	Ecological District	River Environment Classification	300 level FWENZ
1-TW	Port Hills District	CD/L/VB/P/LO/HG	C8.1a
2-TW	Port Hills District	CD/H/VB/P/LO/HG	C8.3a
3-L	Port Hills District	CD/L/M/P/LO/HG	C1.2a
4-L	Port Hills District	CD/L/VB/P/LO/HG	C1.2a
5-L	Port Hills District	CD/L/VB/P/LO/HG	C1.2a
6-L	Port Hills District	CD/L/VB/P/LO/HG	C1.2a
7-TW	Herbert District	CD/L/VB/P/MO/MG	C6.4a
8-TW	Herbert District	CD/L/VB/P/MO/HG	C8.1a
9-L	Herbert District	CD/L/VB/P/MO/MG	C5.2c
10-TW	Herbert District	CD/L/VB/P/MO/LG	C8.6a
11-L	Herbert District	CD/L/M/P/LO/HG	C1.2a
12-TW	Herbert District	CW/H/VB/P/LO/HG	C8.1a
13-W	Herbert District	CW/H/VB/P/LO/HG	C5.2c
14-W	Herbert District	CW/H/VB/P/MO/HG	C5.2c
15-SB	Akaroa District	CD/H/VB/P/LO/HG	C1.2a
16-W	Akaroa District	CD/H/VB/P/LO/HG	C5.2c
17-W	Akaroa District	CD/L/VB/P/MO/MG	C6.4b
18-OBN	Akaroa District	CW/L/VB/P/MO/MG	C5.2c
19-SB	Akaroa District	CW/H/VB/P/MO/MG	C6.4b
20-OBN	Herbert District	CW/L/VB/P/LO/HG	C5.2c
21-W	Akaroa District	CW/H/VB/P/LO/HG	C5.2c
22-W	Akaroa District	CD/H/VB/P/LO/HG	C5.2c
23-W	Herbert District	CW/H/VB/P/MO/HG	C5.2c
24-SB	Akaroa District	CD/H/VB/P/LO/HG	C1.2a
25-SB	Akaroa District	CW/H/VB/P/LO/HG	C1.1c
26-OBN	Herbert District	CW/H/VB/P/MO/HG	C5.2c
27-A	Akaroa District	CW/H/VB/P/LO/HG	C1.1b
28-SB	Akaroa District	CD/H/VB/P/LO/HG	C1.2a
29-OBN	Herbert District	CW/H/VB/P/LO/HG	C5.2c
30-A	Akaroa District	CD/L/VB/P/MO/HG	C5.2c
31-A	Akaroa District	CD/L/VB/P/LO/HG	C1.2a
32-A	Akaroa District	CW/L/VB/P/LO/HG	C1.1b
33-OBN	Akaroa District	CD/L/VB/P/MO/MG	C5.2c
34-A	Akaroa District	CD/L/VB/P/MO/LG	C5.2c
35-A	Akaroa District	CW/L/VB/P/MO/HG	C5.2c
36-OBE	Akaroa District	CW/H/VB/P/MO/MG	C5.2c
37-A	Akaroa District	CW/L/VB/P/MO/MG	C5.2c
38-A	Akaroa District	CW/H/VB/P/LO/HG	C1.1b
39-A	Akaroa District	CW/H/VB/P/MO/HG	C1.1b
40-OBE	Akaroa District	CW/H/VB/P/LO/HG	C1.2a
41-OBN	Herbert District	CD/L/VB/P/LO/MG	C5.2c
42-A	Akaroa District	CW/L/VB/P/LO/HG	C5.2c
43-OBE	Akaroa District	CW/L/VB/P/MO/HG	C5.2c
44-A	Akaroa District	CW/H/VB/P/LO/HG	C1.2a
45-OBE	Akaroa District	CW/L/VB/P/LO/HG	C1.1b
46-OBE	Akaroa District	CW/H/VB/P/LO/HG	C1.2a
47-OBE	Akaroa District	CW/L/VB/P/MO/MG	C5.2c
48-OBE	Akaroa District	CW/H/VB/S/MO/HG	C5.2c
49-OBE	Akaroa District	CW/L/VB/P/LO/MG	C1.1b
50-OBE	Akaroa District	CW/H/VB/S/LO/HG	C5.2c
51-OBE	Akaroa District	CW/H/VB/P/LO/HG	C5.2c
52-OBE	Akaroa District	CW/L/VB/P/MO/MG	C5.2c
53-OBE	Akaroa District	CW/L/M/P/LO/HG	C1.2a
54-OBE	Akaroa District	CD/L/VB/P/LO/HG	C1.2a

Appendix 8: Stream invertebrate data

Table A4: Stream invertebrate relative abundance data per stream.

		1-TW	2-TW	3-L	4-L	5-L	6-L	7-TW	8-TW	9-L	10-TW	11-L	12-TW	13-W	14-W	15-SB	16-W	17-W	18-OBN	19-SB	20-OBN	21-W	22-W	23-W	24-SB	25-SB	26-OBN	27-A
ACARI			4	8	1		3			2	1	3	3	1	3	1			1		10	1		1			6	
AMPHIPODA	*Paracalliope* sp.			4	132																	13						
ANNELIDA			17	32	20		21	7	1	2	6	32	2		3	2	4		6	1	13	20		11	2	17	8	
CARIDEA	*Paratya curvirostris*										2										1							
CLADOCERA												1																
COLEOPTERA	*Antiporus* sp.																											
	Cylomissus sp.														3													
	Elmidae							1							1													
	Hydrophilidae		3	11											4									1	1			
	Ptilodactylidae							3												4		1			3		8	
	Orchymontia banksiana							3	8	3	7		17	3	22		1	12	1				50	26	8		14	15
	Scirtidae		7	7	1											1						1						1
COLLEMBOLA															2													
CRUSTACEA	Ostracoda		1	4			99	8	45	6	1	21	2	3	104				21	1	19	52	3		4			
DIPTERA	*Aphrophila neozelandica*							1	4	3	2		5	10	16			2	1				5	14	27		14	
	Austrosimulium spp.		1	3			2	1162		94	337	2	1	3	1	8	1	101	60	32	190	2	3	4	1	86		33
	Ceratopogonidae																							1				
	Chironominae	21	4	15		9		32	10	3	7	28	16		19	26	11		115	1		6	7	7	4	3	12	
	Culex spp.	3																										
	Diamesinae		1					41			8								87	12							6	
	Empididae		1													1										2	1	
	Ephydridae type B																											
	Eriopterini																											
	Hexatomini			1											2													
	Limonia sp.				2				1						1				1									
	Molophilus spp.																							3				
	Muscidae																											
	Neocurupira chiltoni									11	3		19	4	6		4	229	57	18	11		75	10	22		42	
	Nothodixa spp.	1	3	7			33		2	1	4	5	3	1	7		2	1			2	2		4	1	2	5	2
	Orthocladiinae		36	108	38	4	8	273	20	55	60	31	52	3	41	7	9	12	61	34	3	6	23	44	15	81	60	13
	Paradixa spp.																	1			3							
	Psychodidae		3												1						3	1					1	
	Tanyderidae			1	7										5					2								
	Tanypodinae		6	12	4	19	23	14	82	5	17	3	20	8	28	5	56	4	56	8	2	8	25	5	3	6	10	1
	Thaumaleidae		2												7							4		2				
	Zelandotipula spp.																											
EPHEMEROPTERA	*Atalophlebioides cromwelli*										33																	
	Austroclima jollyae		34	5				1	4		6		18	1	24	10	2	3	2	4			12	51	12	59	36	33
	Coloburiscus humeralis			21				2	256	7	37		23	53	153		20	24	1	2	2	45	97	193	285	14	79	9
	Deleatidium spp.	17	14	106	138	37		201	112	85	159	22	45	66	44	2	39	77	12	22	41	101	91	88	88	38	133	12
	Ichthybotus bicolor									1																		
	Neozephlebia scita	2	100	140	4			3	67	7			32	15	34	11	10	2				200	1	18		1	1	8
	Nesameletus ornatus																										3	
	Nesameletus vulcanus								1				1	6	1	1	3					5		5	1	14	7	16
	Zephlebia spp.								7				9				2		1	1			1				4	
ISOPODA	*Austridotea* sp. A																											
MEGALOPTERA	*Archichauliodes diversus*							1	4	2			3	3	10			9	2	3	2	1	3	4	14		16	
MECOPTERA	*Nannochorista philpotti*		31	3											1							18			1	5		5
MOLLUSCA	*Austropeplea* spp.							1																				
	Gyraulus sp.											1																
	Physa spp.											1																
	Potamopyrgus antipodarum	18	2	43	46	1	1129	18		135	347	421		2	29	13	8	51	197	279	2786	94	2	64	84	1	55	52
	Sphaeriidae		4						20						2		4		1		2	1						
NEMATODA												1																
NEMATOMORPHA																												
PLATYHELMINTHES				56					15		3			2	5	1	3					41		18	1	12		16
PLECOPTERA	*Acroperla trivacuata*								1		1				3								1					
	Austroperla cyrene		38	10					2				3	7	9		2					4	1			1	1	8
	Megaleptoperta diminuta		2								7																	
	Stenoperla prasina												1	2								3						
	Zelandoperla decorata										5		3		1			4	2	2		3	7	3	28		15	
	***Zelandoperla* sp. 1 (BJF00160; Banks Peninsula)**												1			2										15		1
	Zelandobius wardi		13								4		1	34	2	1						6		2		4	1	28
TRICHOPTERA	*Aoteapsyche* spp.			2				7	15	27	12		7	15	15		8	72	24	10		2	11	12	118	1	11	
	Confluens olingoides														1								7				3	
	Costachorema peninsula												2		2			2					1	2	4		1	
	Helicopsyche sp.									84	187		23		10			3	22		7		9	20	5		43	
	Hudsonema alienum						1											1					3					
	Hudsonema amabile						2	2		1	1								3	6	3							
	Hydrobiosella mixta					2			19		2		2	1							1			4	2		4	1
	Hydrobiosis gollanis																								1			
	Hydrobiosis parumbripennis				1			26	1	2	7		2		1			3	6	5			1	5	3		3	
	Hydrobiosis soror							1	1	2	2		1	2	2			3		1		2	3	3	2		3	
	Hydrobiosis spp. (early instar)	1	1	12	1			2		2	13	3	9	1	7		2	2	7	8		4	7	2	3		5	4
	Hydrobiosis styx			17								3	4		1	3	2					1		2		12		
	Hydrobiosis umbripennis																											
	Hydrochorema crassicaudatum																							3				
	Hydrochorema spp. (early instar)																			8								
	Neurochorema confusum							19				2							16	1								
	Neurochorema spp. (early instar)	3				1													10	6	1		1				2	
	Oeconesus spp.			1					1						1							7					1	1
	Olinga spp.			10				12	66	142	162	1	19	2	23	1	4	113	62	55	17	18	95	19	126		14	
	Oxyethira albiceps											14									17							
	Philorheithrus agilis		1	2	8				3					1	1		1				1		1	1	1	3	3	1
	Plectrocnemia maclachlani							1																				
	Polyplectropus sp.	43		7	2	3			24					1			6		1			8	2		5	5	3	
	Pseudoeconesus spp.																2											
	Psilochorema spp.		6	4			3	25	2	10	7	3	1		4		2	1	2	6	1	4		4	8		2	1
	Pycnocentria evecta							12		69	70							35	68	44	52		1		6		9	
	Pycnocentria sp. A		2													1												
	Pycnocentria funerea							3			53							59	136	126	75		1	3			15	
	Pycnocentrodes aeris							42		3	110							23	12	21	4		7	7	8		43	
	Tiphobiosis sp.																							2				
	Triplectides obsoletus													1			1		1	1		10					6	
	Zelolessica cheira	3															2							2		11		

Table A4 continued

		28-SB	29-OBN	30-A	31-A	32-A	33-OBN	34-A	35-A	36-OBE	37-A	38-A	39-A	40-OBE	41-OBN	42-A	43-OBE	44-A	45-OBE	46-OBE	47-OBE	48-OBE	49-OBE	50-OBE	51-OBE	52-OBE	53-OBE	54-OBE
ACARI				1						1			2				4		1	2	1			6		2		
AMPHIPODA	*Paracalliope* sp.			1								12						3					1					1
ANNELIDA			5	3	3		5	5	19	8	25	2	3	5	4	19	19	3		2	2	5		9		9	7	36
CARIDEA	*Paratya curvirostris*										1																	
CLADOCERA																												
COLEOPTERA	*Antiporus* sp.																										6	
	Cylomissus sp.					1																						
	Elmidae	2	1																									
	Hydrophilidae			2	2	1				1						1		2		3		1		3				2
	Ptilodactylidae		8	1					1				1		2	3	11						5			1		1
	Orchymontia banksiana	1	5	10	3	17	1	28	4	13		4	10	14		7	13	17	1	6		16		6	11	3		
	Scirtidae	1			1	1		2						1		2			4	6				4		3		4
COLLEMBOLA																		3						6		8		
CRUSTACEA	Ostracoda		1	1	44	3		3		28	11	6	6	2	44	1	7	3	13		4	2		8		1	7	11
DIPTERA	*Aphrophila neozelandica*		6	3		3	4	10	2	2	4	13	1	1		8	9	8				10	5		8	4		
	Austrosimulium spp.	7	5	17	3	13	265	502	85	7	126	6	4	4	905	5	27	11	49	45	73	3	146			133	6	
	Ceratopogonidae																			1								
	Chironominae	27			37	2	11	1	2	14	6		4	2	4	3	8	5	3	23	8	4	1	15	4	5		4
	Culex spp.																											
	Diamesinae							1	2		4		1		1	4					36		7				49	
	Empididae			1	1			1						3				2		3				1				
	Ephydridae type B																											
	Eriopterini																								1			
	Hexatomini				1													1						1				
	Limonia sp.										1						1	1								1		2
	Molophilus spp.											1											2					
	Muscidae								2										4								1	
	Neocurupira chiltoni		6	53		6	28	136	63	4	44	1	4			22	5	3	7		35	3	33			16		
	Nothodixa spp.		7	5	10	1	3	4	30	1	6	2	2	1	4	1	15	2	9	2		2	2	12	2	38	2	7
	Orthocladiinae	66	20	20	87	19	83	27	55	14	23	15	6	11	29	19	53	31	35	32	150	8	112	60	52	118	90	11
	Paradixa spp.																									2		
	Psychodidae				4				1	1							1	5		1					4			7
	Tanyderidae					1	1		1	1			1									1						
	Tanypodinae	11	10	9	13	9	14	13	10	14	1	15	49	7	9	9	3	4	4	12	6	4		14	1	1		
	Thaumaleidae			3				4	4									1		1	1	2					1	
	Zelandotipula spp.																	1										
EPHEMEROPTERA	*Atalophlebioides cromwelli*																											
	Austroclima jollyae	25	2	31	13	23	2	8	9	17	6	4		7		32	4	29	1	54	1	50	37	59	4	11		
	Coloburiscus humeralis	26	23	29	34	14	16	19	25	57		130	85	63	11	32	18	35	12	127		53	92		17	69	10	
	Deleatidium spp.	60	37	89	46	26	57	28	42	58	21	95	68	43	63	91	74	68	59	71	18	55	30	10	17	105	275	116
	Ichthybotus bicolor																											
	Neozephlebia scita	1	2	2	4	2	21	43	6	18		1	19	1			9	2		5		2		11	4			
	Nesameletus ornatus																											
	Nesameletus vulcanus	19	3		2	1				1		8	25	49		31		26		14		2		16	15			
	Zephlebia spp.	7	1	1			3			6					2													
ISOPODA	*Austridotea* sp. A																											53
MEGALOPTERA	*Archichauliodes diversus*	3	5	11	3	2	3	11	11	3	2	12	12	3		8	12		2			1	2			11	2	
MECOPTERA	*Nannochorista philpotti*	12	2		8							1	2											14	1			1
MOLLUSCA	*Austropeplea* spp.																											
	Gyraulus sp.								2																			
	Physa spp.																											
	Potamopyrgus antipodarum	1	3	137	3	8	78	15	148	2	473	2	4		321	1	164	6	231		174	2	458	89		115	207	195
	Sphaeriidae					1	11			2																	2	1
NEMATODA												1																
NEMATOMORPHA																										1		
PLATYHELMINTHES			3		12				1	3		7	6	1		2	3	11		2		4		47	1	8	3	
PLECOPTERA	*Acroperla trivacuata*																											
	Austroperla cyrene	2	1	9	19	3	1			38		2	2	15				2		3				6				
	Megaleptoperta diminuta																											
	Stenoperla prasina				2							2	1	7				2										
	Zelandoperla decorata		6	11		7		1		3		5			6	11	17		1		4		11			9		
	***Zelandoperla* sp. 1 (BJF00160; Banks Peninsula)**	2	2			1							2					8		2								
	Zelandobius wardi	1			7							3	2	1				10		25		1		17	20	1		
TRICHOPTERA	*Aoteapsyche* spp.	1	6	20	21	4	12	25	19	11	34	14	2	5	18	43	12	1	17		18	7	9		13	61	1	
	Confluens olingoides			3		5																						
	Costachorema peninsula	1		3		2		1	1	1		1	4			1		2		1		3				4		
	Helicopsyche sp.		1	13		3	12	13	19	14	14		11		107	49	6	1	204		89	8	7	10		43		4
	Hudsonema alienum															3	14									1	1	
	Hudsonema amabile						13		1		11				19						8					1		
	Hydrobiosella mixta	1			1	1				1		1				2	4	4	4	21			5			3		
	Hydrobiosis gollanis	1				2																						
	Hydrobiosis parumbripennis			1		1	3	2	5	1	2				11	2	9						12			9	2	
	Hydrobiosis soror		2	1		1	1	1	3	1					1	2	1	2				2				2		
	Hydrobiosis spp. (early instar)	3	2	4	1	10	8	3	3	1	4		6		3	4	1	4	2	7	3		13	13		8	2	2
	Hydrobiosis styx	1	3		4					2		8	1					2		10		2	2	4	2			
	Hydrobiosis umbripennis						1																					
	Hydrochorema crassicaudatum																											
	Hydrochorema spp. (early instar)																											
	Neurochorema confusum								5		10				13						12					4		
	Neurochorema spp. (early instar)			1																							1	
	Oeconesus spp.		2		7	1				2							3		1	1				3	2	1		7
	Olinga spp.	3	3	18	1	12	125	91	71	23	33	26	40	5	76	81	31		137	1	33	13	146			459	9	
	Oxyethira albiceps																				2							
	Philorheithrus agilis					4		5	5		1	1	4	2		1				3		1	1	5	2	2	5	
	Plectrocnemia maclachlani	5																										
	Polyplectropus sp.	28	2				2			3		1	21	1	1	2		2		21		1		1	1			8
	Pseudoeconesus spp.																											
	Psilochorema spp.	3		2			4	6	8		10	1		2	6	3		1	8	1		2	5	5	2	2	5	
	Pycnocentria evecta			8			62	2	39		61		8		50	66	58		3		30		81			269	7	
	Pycnocentria sp. A	1		1																12				3	1		3	18
	Pycnocentria funerea	1	7	15				5	26		61	2			48	22			109		95					150	2	
	Pycnocentrodes aeris		1	15			9	4	1		4				8	2	10		6		6		2			3		
	Tiphobiosis sp.							1																				
	Triplectides obsoletus				1					3				1	1		1		8					4	1			
	Zelolessica cheira				1	1							5				1		1				1					